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ADC TECHNICAL REPORT 3419
Part 1

**SEMITRAILER MOUNTED OXYGEN OR NITROGEN
GENERATING AND CHARGING PLANT**

Part. 1. Design Study

B. W. PARROW

AIR PRODUCTS, INCORPORATED

JANUARY 1984

WRIGHT AIR DEVELOPMENT CENTER

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WADC TECHNICAL REPORT 54-19
Part I

**SEMITRAILER MOUNTED OXYGEN OR NITROGEN
GENERATING AND CHARGING PLANT**

Part I, Design Study

H. J. W. Farrow

Air Products, Incorporated

January 1954

*Equipment Laboratory
Contract No. AF 33(600)-19835
RDO No. 660-128*

*Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio*

FOREWORD

This report was prepared by Air Products, Incorporated, Allentown, Pennsylvania, on contract No. AF 33(600)-19855, dated 9 June 1952; Supplement Agreement No. 1, dated 2 March 1953; and Revision 1, dated 15 May 1953. Work was administered under the direction of C. R. Anderson, Vice-President-in-Charge-of-Engineering and H. W. Farrow acted as project engineer. The contract was initiated under Research and Development Order No. 660-128, "Improvement and Development of Oxygen Generating Plants and Auxiliary Equipment," by the Equipment Laboratory, Directorate of Laboratories, Wright Air Development Center, with A. M. Paulson serving as project engineer.

This is one of a series of three reports to be issued on this project. The second report will be issued upon completion of the operating tests on the mobile, liquid oxygen generator, while the third report will be issued upon completion of the entire program.

Included among those who cooperated in the study were C. J. Schilling, L. L. Volland, P. G. Foust, J. V. Fetterman of Air Products, Incorporated.

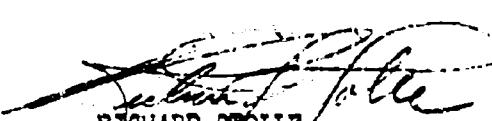
ABSTRACT

Design of a mobile generator capable of producing two tons per day of high-purity liquid oxygen or liquid nitrogen and capable of compressing the entire production capacity to 4000 PSIG as described. Flows of the operating cycle are pictured and discussed. Material and heat balances are calculated on the basis of theory and past experience gained from the fabrication of more than 500 oxygen generators, both mobile and stationary, of high- and low-purity type. Tentative specifications for the equipment components are listed.

PUBLICATION REVIEW

The publication of this report does not constitute approval by the Air Force of the findings or the conclusions contained therein. It is published only for the exchange and stimulation of ideas.

FOR THE COMMANDER:



RICHARD SPOLIE
Colonel, USAF
Chief, Equipment Laboratory

SUMMARY

To obtain the desired production of two tons per day of 99.5% pure liquid oxygen, or two tons per day of 99.0% pure liquid nitrogen, an air feed of approximately 1000 standard cubic feet per minute shall be used. This shall indicate a liquid oxygen recovery by weight of 4.2% or a liquid nitrogen recovery by weight of 3.7%. To operate the unit three diesel engines shall supply approximately 330 horsepower, which shall result in a ratio of approximately 1.1 pounds of liquid oxygen produced per pound of diesel fuel burned. A temperature approach of approximately $50^{\circ}F$ shall be expected at the air inlet and of the heat exchanger. The estimated heat infiltration from ambient surroundings into the air separator shall be 1.5 B.T.U. per pound of air feed. It is estimated that the loss of air from the heat exchanger during the reversals, which occur every 10 minutes, shall be 3% of the total input. The semitrailer shall be approximately 32'-0" long, 9'-6" wide and 12'-0" high. These dimensions, which are reduced to a minimum, shall be for the greater part, dictated by the availability of equipment components in the air source section.

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SECTION I
CYCLE OF AIR SEPARATION

General

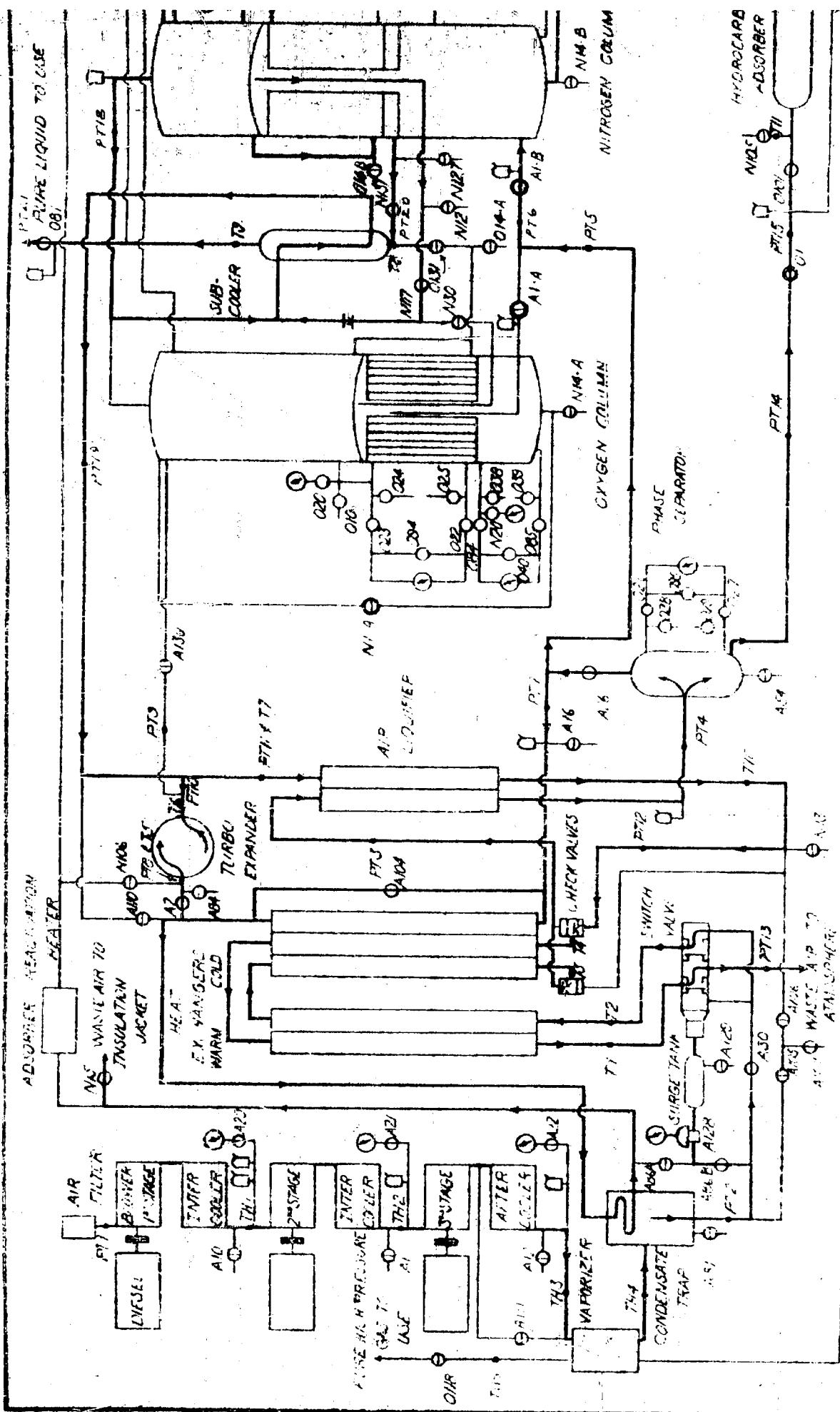
The cycles of air separation for this generator are pictured on four Air Products, Incorporated Drawings numbered 42559, 42560, 42561 and 42562. Each will illustrate a phase of operation and will herein be referred to as Figures 1, 2, 3 and 4. The liquid product is produced by the distillation of liquid air into pure oxygen or nitrogen dependent on requirements. Atmospheric air which forms the raw material is filtered, compressed, freed of water vapor and carbon dioxide in reversing heat exchangers, and then liquefied by a combination of cooling and expansion. The pure product which results from the distillation of the liquid air is drawn off as a liquid at column operating pressure or, is fed as a liquid into special pumps which compress the product to any pressure up to 4000 PSIA. The cold high-pressure liquid product leaving the pump is warmed in a heat exchanger, and flows as a gas into cylinders or into some other receiver. Since this product is the result of distillation of liquid air, it can be considered absolutely dry for all conditions of use.

It is necessary to remove the water vapor and carbon dioxide contents from the air inasmuch as these impurities, if not removed, would, in a relatively short period of time, "freeze out" at the sub-zero temperatures involved and thus plug lines and render the generator inoperative.

Detailed Description

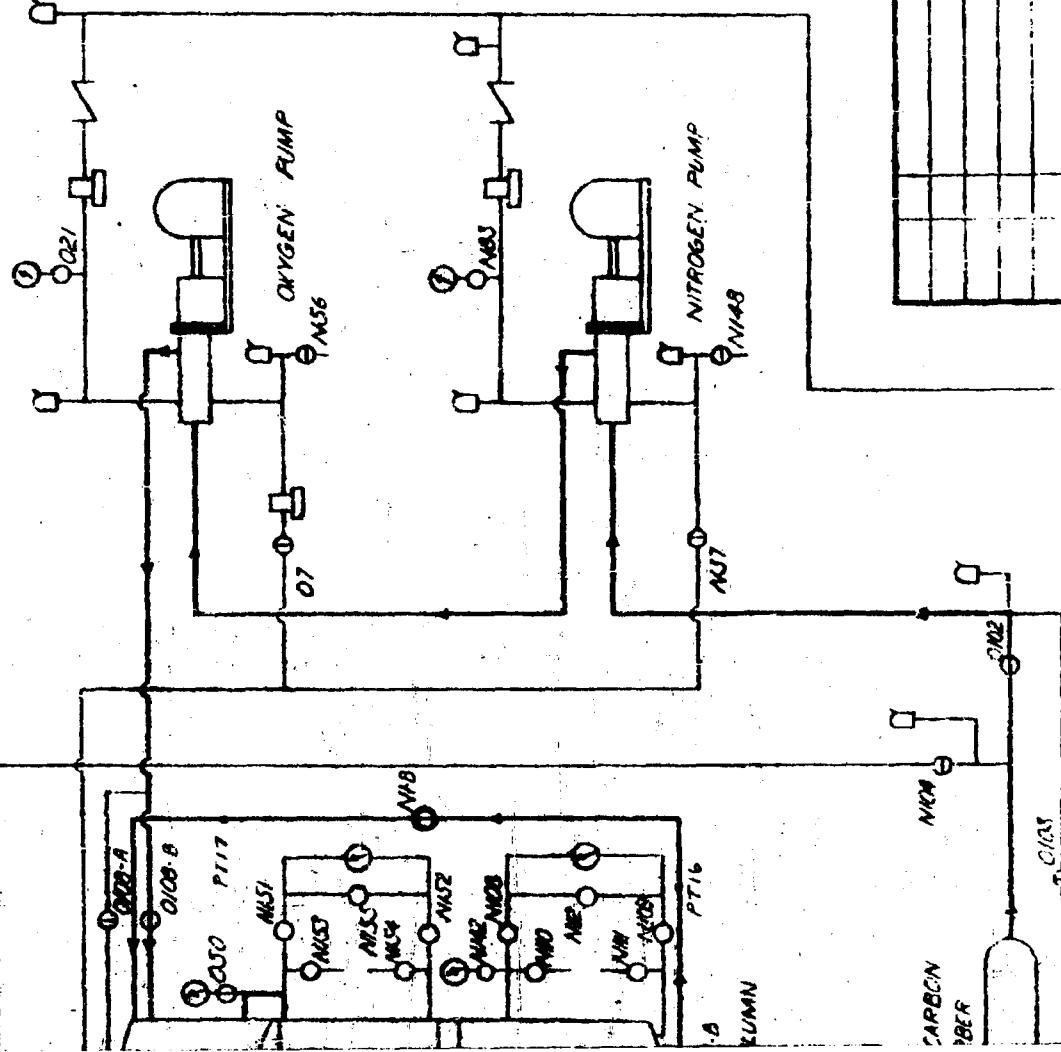
Atmospheric air is drawn through mechanical filters to remove any foreign matter which may be injurious to the equipment, and is then fed to an oil-free air compressor where its pressure is elevated to 100 PSIG. The air compressor is a three-stage unit, each stage consisting of a rotary blower which is direct-driven by a diesel engine through a suitable transmission. Some moisture, and also the heat of compression, are removed from the air in air-cooled inter- and aftercoolers.

The "high-pressure" air is then fed to the heat exchanger through a switch valve. This valve switches or reverses, at preset ten minute intervals, the heat exchanger passes for the incoming, high-pressure air and the effluent, low-pressure, waste air such that, the passes which were high-pressure air passes for the previous ten minutes then become effluent, waste air passes for the next ten minutes, and vice-versa. The remaining moistures, and also the carbon dioxide, in the high-pressure air are deposited in the heat exchanger at the different temperature levels which are in equilibrium with the vapor pressures and concentrations of the moisture and carbon dioxide. These deposits are made in the two passes alternately. While a deposit is being made in one pass, the deposit in the other pass is being "cleaned up" through the absorptive capacity of the dry, low-pressure, effluent, waste air.



Schematic
 VALVE OPEN
 VALVE STAND
 EXPANSION VALVE
 CHECK VALVE
 JACKET PIPE VALVE
 TANK
 PRESSURE GAUGE
 FILTER

⑤ LIQUID LEVEL GAUGE
 ⑥ PRESSURE GAUGE
 ⑦ LIQUID LEVEL GAUGE
 ⑧ LIQUID LEVEL GAUGE
 ANALOG READOUT

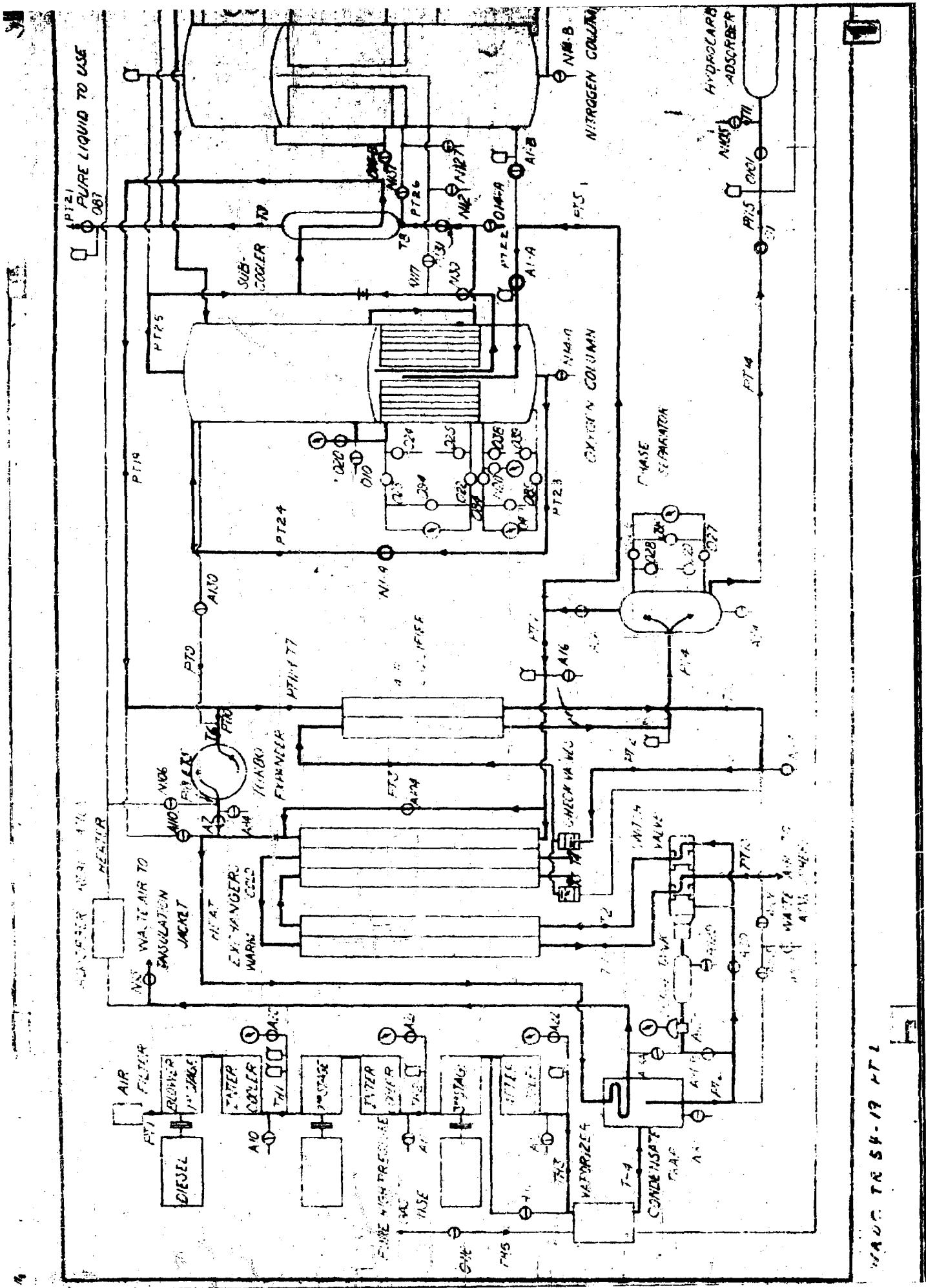


AIR PRODUCTS, INCORPORATED
DEPT. PLANT, U.S.A.

ASSEMBLY	ITEM	DESCRIPTION	QTY
1	LIQUID LEVEL GAUGE	LIQUID LEVEL GAUGE	1
2	PRESSURE GAUGE	PRESSURE GAUGE	1
3	LIQUID LEVEL GAUGE	LIQUID LEVEL GAUGE	1
4	LIQUID LEVEL GAUGE	LIQUID LEVEL GAUGE	1
5	ANALOG READOUT	ANALOG READOUT	1

page 2.

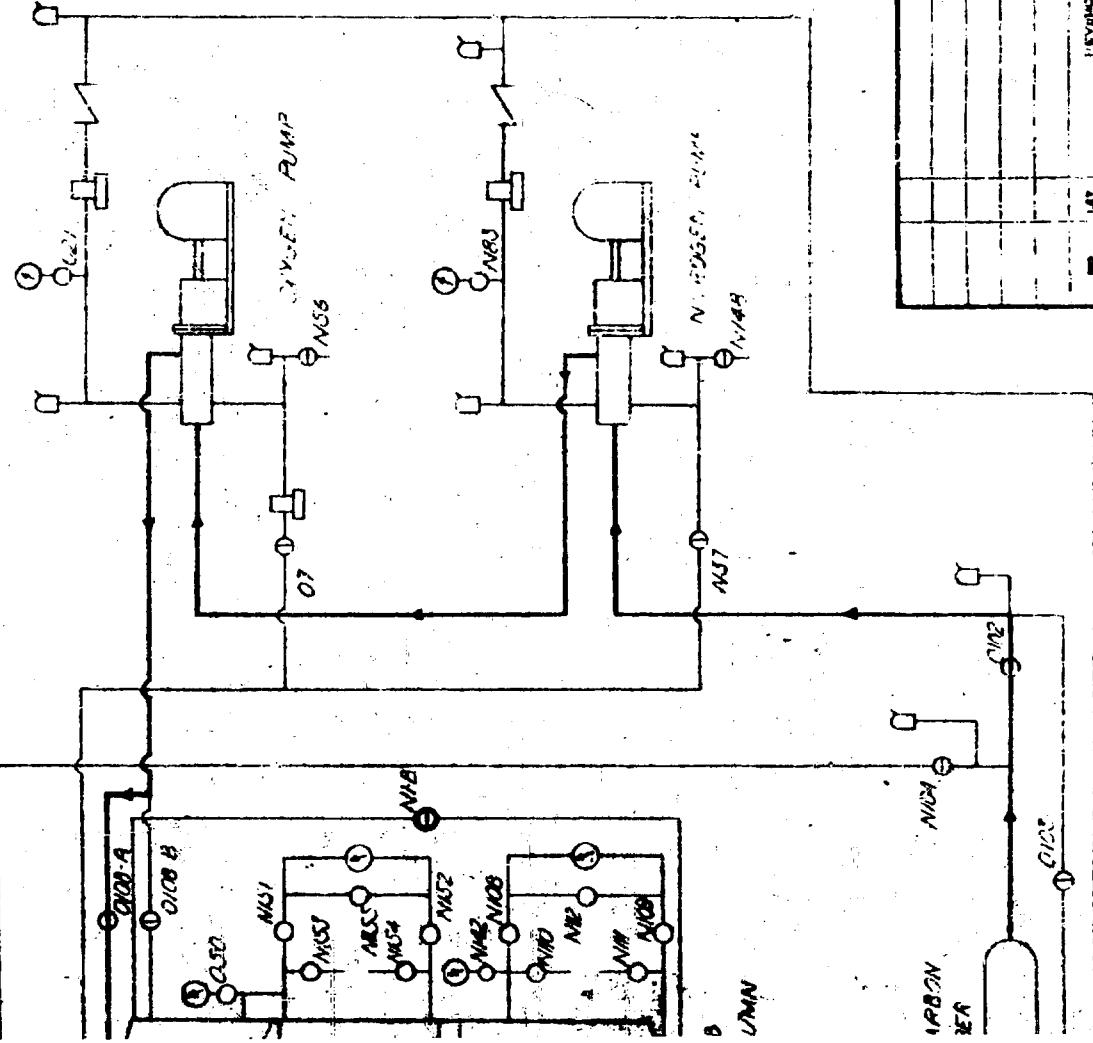
2



EGEN

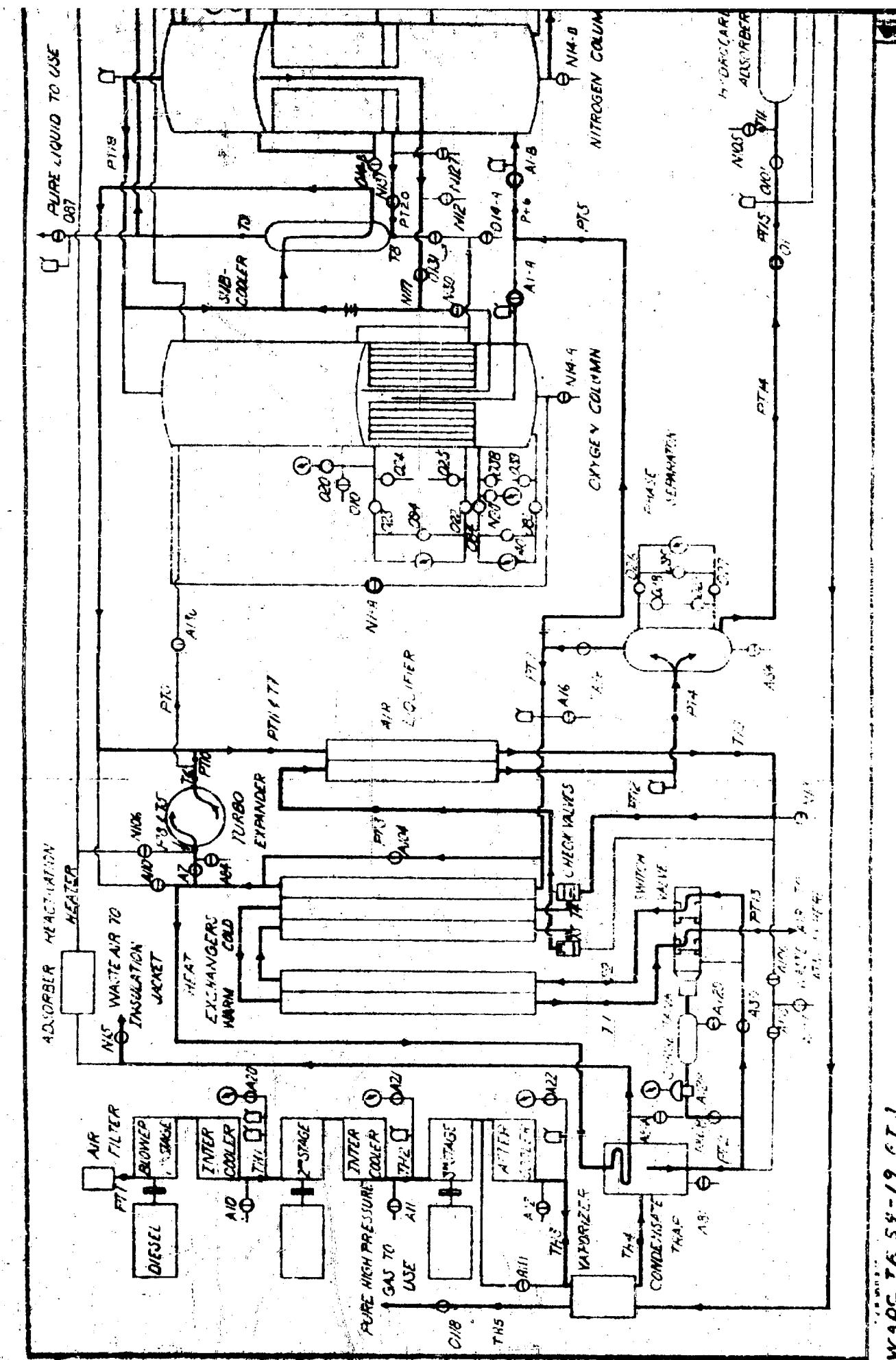
VALVE OPEN	
VALVE CLOSED	
EXPANSION VALVE	
CHICOT VALVE	
SAFETY VALVE	
DRIVER	
PRESSURE GAUGE	
FILTER	

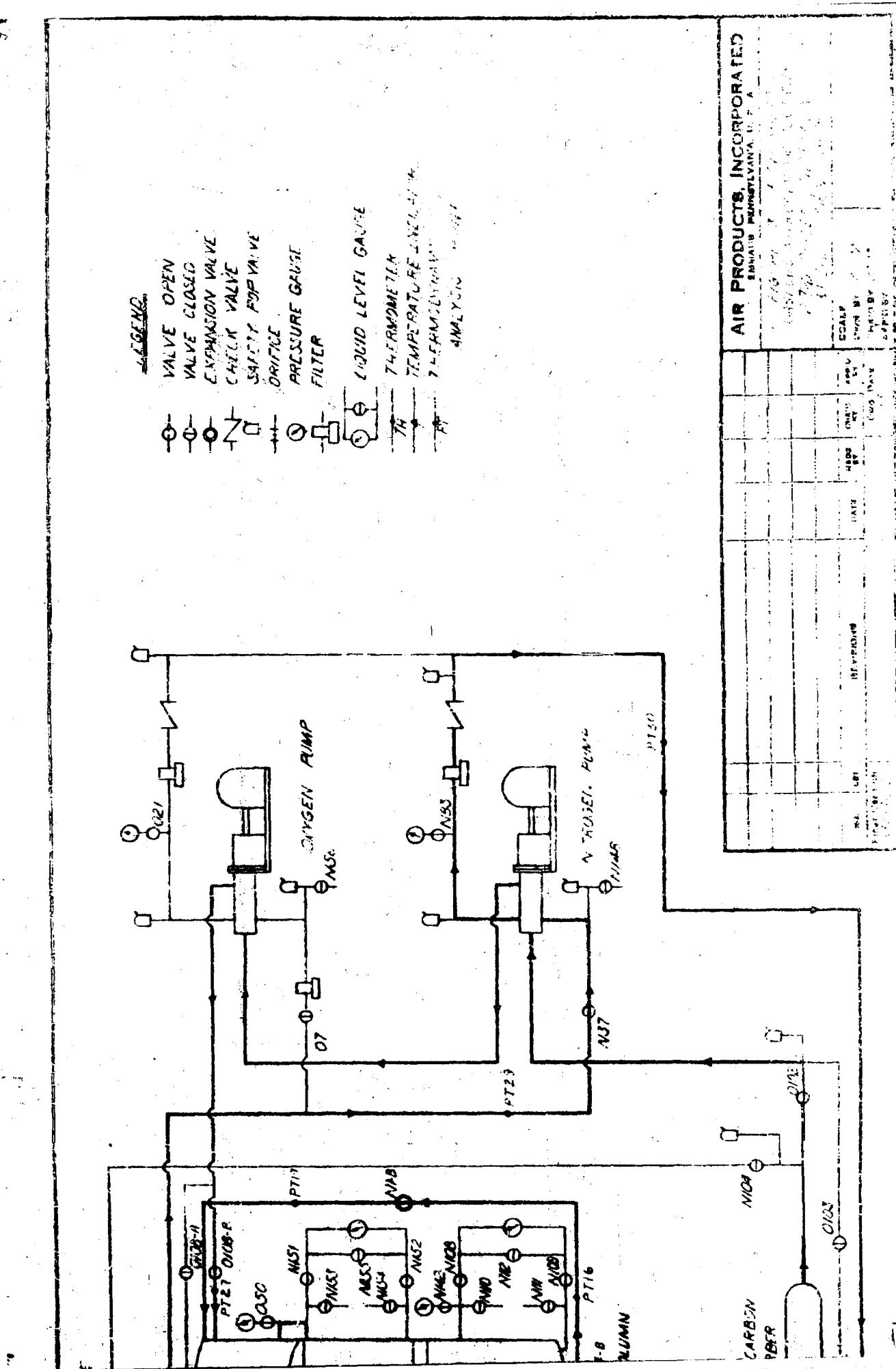
④ LIQUID LEVEL GAUGE
 ⑤ THERMOMETER
 ⑥ TEMPERATURE INDICATOR
 ⑦ PRESSURE DYNAMIC
 ⑧ ANALOG DIA



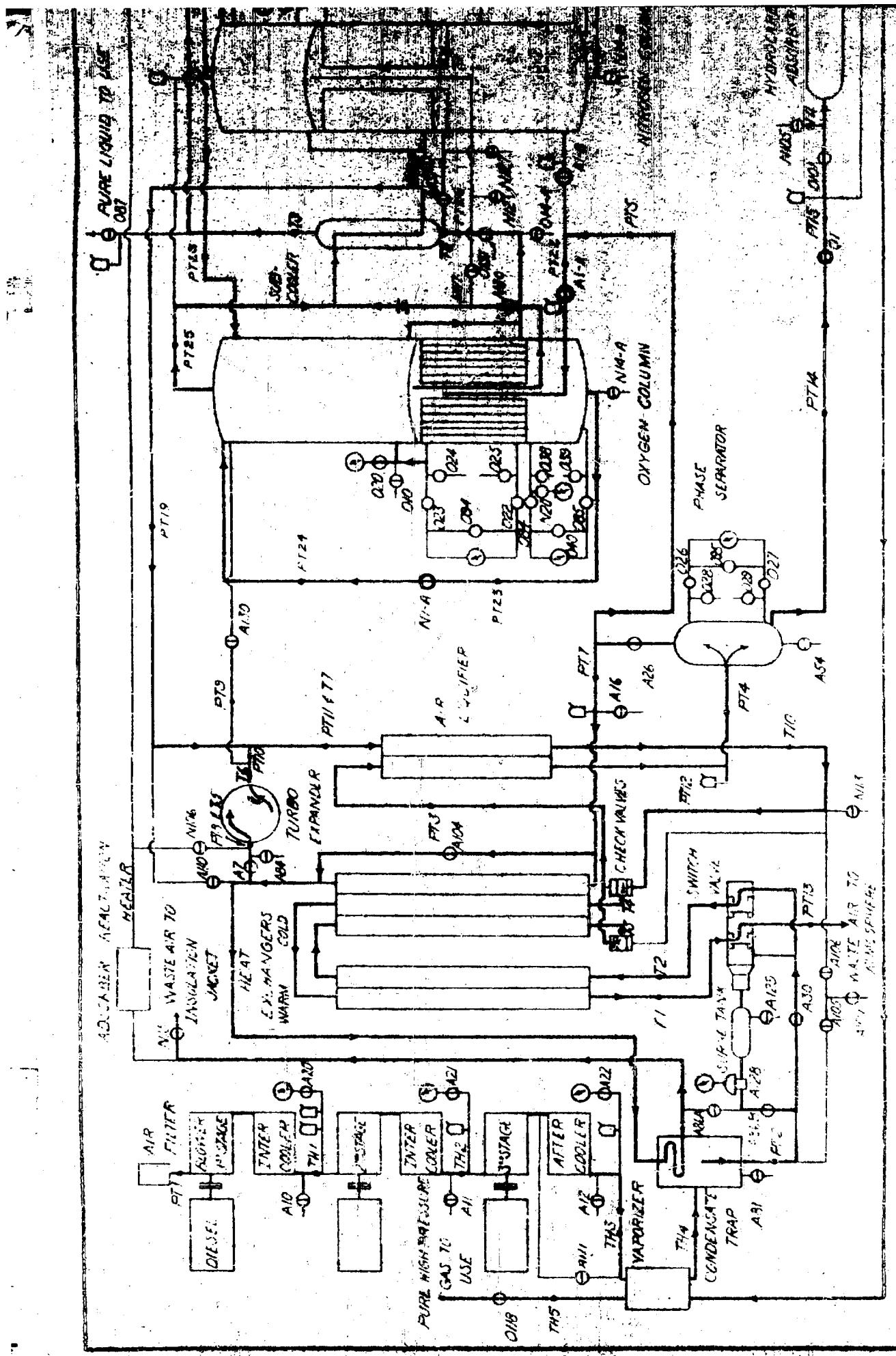
AIR PRODUCTS, INCORPORATED
PHILA'D'VA., PENNSYLVANIA, U.S.A.

2 FIGHT STREET
BLIND OFFICE PRODUCTION
222 BROADWAY
NEW YORK 7-4747
214 EAST 74TH STREET





AIR LIFTING TO
OXYGEN



WATER TRAP 56195 PT7-4

AIR PROCESS INCOMPRESSOR

FIGURE 1 TYPICAL SHEET		FIGURE 2 GASOLINE OXYGEN PRODUCTION		FIGURE 3 OXYGEN/NITROGEN MOBILE GENERATOR	
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80389					

After leaving the heat exchanger, the high-pressure air, which is then a saturated vapor, enters the air liquefier. The liquefier is an extension of the heat exchanger surface, and in it, liquefaction of a portion of the incoming air is effected. This portion is the amount of liquefaction necessary to keep the cycle operating, and it is equivalent to, (1) the amount of liquid withdrawn as the final product plus, (2) the amount of liquid which is vaporized as a result of the influx of heat into the generator from the ambient surroundings plus, (3) the amount of liquid which is lost as a result of the expansion from high-pressure-air pressure to column operating pressure, the pressure at which the liquid product is withdrawn.

The partially liquefied, high-pressure air then enters the phase separator, where its liquid and vapor phases are divided and directed into different streams.

The liquid stream is expanded to approximately 6 PSIG after which it is passed through a silica gel type hydrocarbon adsorber. In the adsorber, removal of the hydrocarbon content is accomplished to prevent their accumulation to dangerous concentrations in the distillation column. After every 150 or more hours of operation, the adsorber is reactivated by means of an electrically heated stream of hot dry air which absorbs the hydrocarbons and carries them off to atmosphere. This air is tapped from the air supply to the turbo expander.

After the adsorber the liquid stream is fed to the sub-cooling jackets of the liquid product pumps to prevent vaporization of the pure liquid product when the pump is operating, and thus keep the pump efficiency high. The stream is then directed to the low pressure section of either the nitrogen or oxygen column depending on the final product required.

The vapor phase is further divided into two streams. One of these, representing 75% of the total air feed, passes through the cold section of the heat exchanger from the cold end to the warmer end, and then feeds the turbo expander. The exhaust from the expander joins the effluent waste air stream which leaves the column and enters the air liquefier.

In the case of producing oxygen the other vapor stream from the phase separator is expanded through a valve from high-pressure-air pressure to high-pressure column pressure, which is approximately 89 PSIA. This vapor enters the high-pressure column and is fed directly into the condenser where all of it is condensed by the product liquid oxygen which surrounds the tubes on the low-pressure-column side of the condenser. The resulting liquid is expanded to low-pressure-column pressure and introduced into the low-pressure column at the top as reflux. In order to prevent rare, inert gases such as neon, etc., which are found in the air, and which are not capable of being condensed by the liquid oxygen, from blanketing the condenser tube surfaces and thus impair their efficiencies, a stream is drawn off from the dome of the condenser and expanded into the effluent waste air stream which leaves the column. This non-condensable offtake, although very effective in accomplishing its purpose, is so very small in magnitude that it does not enter into the calculations for the material and heat balances.

The low-pressure column contains a number of bubble-cap pans of conventional design, which are fed at the proper points by the expanded liquid from the

incoming high-pressure air, and the expanded liquid from the high-pressure column. The liquid descending on these pans comes into intimate contact with the ascending vapors resulting from the column feeds as well as the vapors from the boiling oxygen which surrounds the tubes of the condenser. This intimate contact of vapor and liquid on each pan results in a gradual vaporization of the more-volatile constituent, nitrogen, and a condensation of the less-volatile constituent, oxygen. Sufficient pans are included in the low-pressure column to ensure that the liquid withdrawn from the bottom is 99.5% pure oxygen. Because the boiling point of argon is closer to the boiling point of oxygen than it is to the boiling point of nitrogen, it appears in the column in the vicinity of the oxygen, and shows up as the 0.5% impurity in the product oxygen.

Since there is only one product, oxygen, withdrawn from the column, the remaining oxygen and argon and all of the nitrogen leave the column at the top as a saturated vapor. This vapor passes through the oxygen subcooler where it sub-cools the product oxygen to prevent or reduce "flash" losses resulting from later expansion. After passing through the subcooler, it combines with the turbo expander exhaust and enters the air liquefier where it liquefies a portion of the incoming high-pressure air. From the air liquefier it passes through the heat exchanger where it both cools the incoming air to saturation temperature, and absorbs the moisture and carbon dioxide which were deposited by the incoming air during the preceding ten-minute switch period. It finally exhausts to atmosphere through the switch valve.

The product liquid oxygen is withdrawn from the bottom of the low-pressure column. It passes through the subcooler where it is subcooled by the effluent waste air to prevent or reduce "flash" losses resulting from expansion into the reciprocating oxygen pump, or into an external receiver. In the pump its pressure is elevated to 4000 PSIG and it is discharged through a heat exchanger or vaporizer in the discharge line of the third-stage blower where it is warmed to ambient temperature.

In the case of producing nitrogen the other vapor stream from the phase separator is expanded through a valve from high-pressure-air pressure to high-pressure column pressure, which is approximately 52.2 PSIA. The vapor enters the high-pressure nitrogen column which contains a number of bubble-cap pans of conventional design. The ascending vapor comes into intimate contact with liquid descending on the pans. This intimate contact of vapor and liquid on each pan results in a gradual vaporization of the more volatile constituent, nitrogen and a condensation of the less volatile constituent, oxygen, which is expanded into the low pressure column. The ascending vapor enters the condenser where it is condensed to a liquid nitrogen product by the crude oxygen product which surrounds the tubes on the low pressure column side of the condenser. As in the case of oxygen production a small noncondensable stream is removed from the dome of the condenser to prevent blanketing of the condenser surface.

The low pressure column consists essentially of a condenser and shell. The expanded crude oxygen from the high pressure column and the expanded liquid stream

from the product pump racks are introduced into the low pressure column side of the condenser. These streams are vaporized by the condensing nitrogen in the high pressure column and the resulting vapor passes through several entrainment trays above the condenser in the low pressure column.

The waste vapor from the low pressure column passes through the subcooler. After passing through the subcooler, it combines with the turbo expander exhaust and enters the air liquefier where it liquefies a portion of the incoming high-pressure air. From the air liquefier it passes through the heat exchanger where it both cools the incoming air to saturation temperature, and absorbs the moisture and carbon dioxide which were deposited by the incoming air during the preceding ten-minute switch period. It finally exhausts to atmosphere through the switch valve.

The product liquid nitrogen is withdrawn from the bottom of the condenser. It passes through the subcooler into the reciprocating nitrogen pump, or into an external receiver. In the pump its pressure is elevated to 4000 PSIA and it is discharged through a heat exchanger or vaporizer in the discharge line of the third-stage blower where it is warmed to ambient temperature.

Pressure gauges, liquid-level gauges and temperature indicators are located throughout the system as necessary to serve as operating aids. In addition, all circuits in the cycle are protected against excess pressure by means of pop safety valves.

After 150 or more hours of operation, accumulation of moisture and carbon dioxide deposits may require that the generator be defrosted or derimed. To accomplish this, numerous outlets are provided at desired locations to vent the defrost air to atmosphere.

Should ambient air penetrate the air separator insulation jacket, its moisture content would be deposited upon the cold surfaces of the components and also upon the cold fiberglass insulation. To prevent this, the insulation jacket is put under a slight, positive pressure by means of a small stream of dry, nitrogen-rich air which is tapped from the turbo expander supply line and warmed in a coil inside the condensate trap.

SECTION II
ELECTRIC POWER AND CONTROL

The electric power and control circuits of this generator are pictured in Figure 5, Air Products, Incorporated Drawing No. 42563, Single Line Wiring Diagram.

The electric power required by the product pumps, the hydrocarbon adsorber reactivation heater, switch valve timing control, and lighting is furnished by a 18.7 Kva, 120/208 volt, 3 phase, 4 wire, 60 cycle synchronous generator with direct connected exciter and automatic voltage regulator as an integral part of its frame. This alternating current generator is driven at 1800 RPM through a V-belt drive by one of the diesel engines in the air compressing section.

Power is distributed throughout the trailer from a control center which contains a three-phase main service circuit breaker for the circuit from the a-c generator; a combination three-phase starter for the pump motors; a three-phase circuit breaker and control for the hydrocarbon adsorber reactivation heater; and branch circuit breakers for the 120 volt single phase timing control, lighting, and power receptacle circuits.

Emergency lighting, alarm circuits for diesel engine cooling water and oil pressure indication, and emergency engine shut-down control are energized from the 24-volt d-c storage battery furnished for starting the diesel engines. This bank can be charged by one of the generators on either of two of the engines.

SECTION III

THERMODYNAMIC CALCULATIONS

The sources of thermodynamic data for this report were: Miller & Sullivan, U. S. Bureau of Mines, Mollier Charts of 1928; and V. C. Williams, Northwestern University.

The material balance of this cycle is based upon the following composition of atmospheric air: 21% oxygen, 78% nitrogen, and 1% argon.

The term "standard cubic feet per minute", abbreviated SCFM, as used in this report means one cubic foot of gas at the standard conditions of 70°F and 14.7 PSIA.

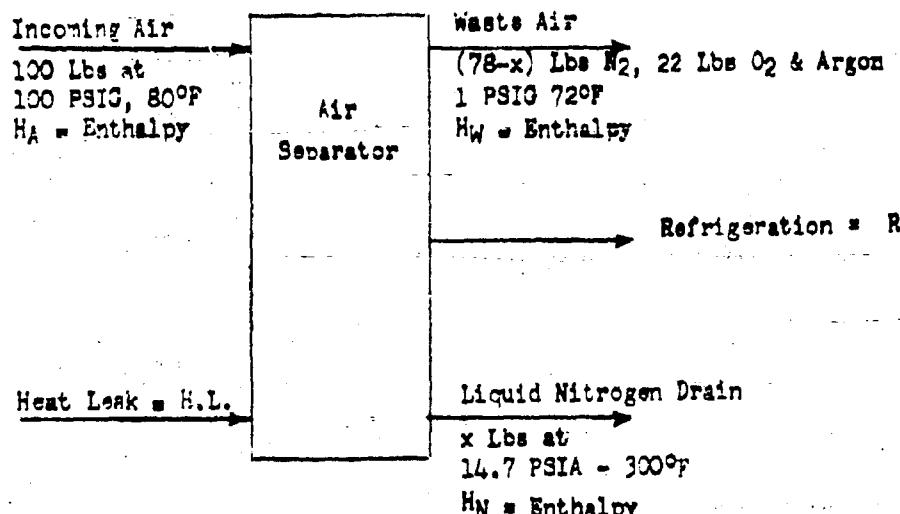


Figure 6 Liquid Nitrogen Generator Heat Balance

Refrigeration, R

The refrigeration available results from the expansion of approximately 75% of the incoming air from 112 PSIA to 21 PSIA. For the expander to have an adiabatic efficiency of 72% the assumed inlet temperature is -240°F

$$\begin{aligned}
 H_1 &= \text{Enthalpy At Inlet Conditions } 112 \text{ PSIA } -240^{\circ}\text{F} \\
 &= 104.50 \text{ Btu/Lb}
 \end{aligned}$$

$$\begin{aligned}
 H_{\text{0 isen}} &\approx \text{Enthalpy at Expander Exhaust for 100\% Expander Efficiency} \\
 &= 85.58 \text{ Btu/Lb}
 \end{aligned}$$

$H_0 \text{ act}$ = Enthalpy At Actual Exhaust Conditions

$$= 90.93 \text{ Btu/Lb}$$

$$\text{Efficiency} = \frac{H_1 - H_0 \text{ act}}{H_1 - H_0 \text{ isen}} \times 100$$

$$= \frac{104.5 - 90.93}{104.5 - 85.58} \times 100 = 71.72\%$$

This checks the anticipated value

$$R = H_1 - H_0 \text{ act}$$

$$= 104.5 - 90.93$$

$$= 13.57 \text{ Btu/Lb}$$

Since only 75% of the incoming air is to be expanded

$$R = 0.75 \times 13.57$$

$$= 10.18 \text{ Btu/Lb}$$

For 100 lbs.

$$R = 1018 \text{ Btu}$$

Enthalpy of Incoming Air, H_A

At the conditions of 100 PSIG & 80°F the heat content of 100 lbs. of entering air will be

$$H_A = 18,430 \text{ Btu}$$

Enthalpy of Liquid Nitrogen, H_N

At the conditions of 14.7 PSIA and -298°F the enthalpy of liquid nitrogen is (Equivalent of 3.55 ATM SAT.)

$$H_N = 12.02 \text{ Btu/Lb}$$

For x lbs. the heat content will be

$$H_N = 12.02 x$$

Heat Leak, H. L.

The anticipated heat leak is taken as

$$H.L. = 1.5 \text{ Btu/Lb or } 150 \text{ Btu for 100 lbs.}$$

Enthalpy of the Effluent Waste Air, H_W

At the conditions of 1 PSIG & 72°F the enthalpy of the waste air is equal to the sum of the enthalpies of the constituents

The enthalpy of nitrogen at these conditions is

$$H_N = 183.5 \text{ Btu/lb.}$$

Since 78-x pounds of N_2 are exhausted as waste in this case

$$H_N = 183.50 (78-x)$$

$$H_N = 14,313 - 183.5x \text{ Btu}$$

The enthalpy of the oxygen under these conditions is

$$H_O = 181.20 \text{ Btu/lb.}$$

Since all the oxygen is waste

$$H_O = 22 \times 181.20$$

$$H_O = 3,986 \text{ Btu}$$

$$H_W = H_N + H_O$$

$$= 14313 - 183.5x + 3986$$

$$H_W = 18299 - 183.5x$$

Total Heat Balance

The total heat balance will be

$$H_A + H.L. = H_W + R + H_V$$

$$18430 + 150 = 18299 - 183.5x + 12.02x + 1018$$

$$x = 4.30 \text{ pounds } N_2 \text{ produced per 100 pounds Air}$$

Since it is impossible to get sufficient subcooling 14.0% of the liquid nitrogen produced will flash.

The air required for 2 tons per day liquid production is

$$Q = 2 \frac{\text{Tons}/\text{Day}}{\text{(Ton)}} \times 2000 \frac{\text{Lbs}}{\text{(Lbs)}} \times \frac{1}{24} \frac{\text{Days}}{\text{(Hr)}} \times \frac{1}{60} \frac{\text{Hr}}{\text{(Min)}} \times \frac{1}{0.075} \frac{\text{Cubic Ft}}{\text{(Lbs)}} \times \frac{1}{0.0430} \times \frac{1}{0.86}$$

$$Q = 1002 \text{ Assuming a 3% reversal loss}$$

$$Q = 1032 \text{ Say 1035 SCFM}$$

GENERATOR MATERIAL BALANCE

Point 1-N Standard Intake Conditions for Air Compressor

Pressure	14.7 PSIA
Temperature	70°F
Fluid State	Superheated Vapor
Fluid Flow Rate	

$$W_1 = 1035 \times 0.075 \times 60 \times \frac{1}{28.9}$$

$$\approx 161.16 \frac{\text{lb - Mols}}{\text{Hr}}$$

Composition	Flow x Concentration = Composition
-------------	------------------------------------

$$W_{O_2} = 0.21 \times 161.16$$

$$\approx 33.84 \text{ Mols/Hr}$$

$$W_{N_2} = 0.78 \times 161.16$$

$$\approx 125.71 \text{ Mols/Hr}$$

$$W_A = 0.01 \times 161.16$$

$$\approx 1.61 \text{ Mols/Hr}$$

Enthalpy

At 14.7 PSIA and 70°F

$$H_1 = 182.74 \text{ Btu/Lb}$$

Point 2-N Discharge for Air Compressor

Pressure	114.7 PSIA
Temperature	80°F
Fluid State	Superheated Vapor
Fluid Flow Rate	

The 3% switch loss is eliminated for the purpose of calculating a heat balance.

$$W_2 = 156.02 \text{ Mols/Hr}$$

Composition

$$W_{O_2} = 32.76 \text{ Mols/Hr}$$

$$W_{N_2} = 121.70 \text{ Mols/Hr}$$

$$W_A = 1.56 \text{ Mols/Hr}$$

Enthalpy

At 114.7 PSIA and 80°F

$$H_2 = 184.30 \text{ Btu/Lb}$$

Point 3-N High Pressure Air Leaving Heat Exchanger

Pressure 114.7 PSIA

Temperature -272°F

The air leaving the exchanger will be a saturated vapor at
114.7 PSIA

Fluid State Saturated Vapor

Fluid Flow Rate

$$W_3 = 156.02 \text{ Mols/Hr}$$

Composition

$$W_{O_2} = 32.76 \text{ Mols/Hr}$$

$$W_{N_2} = 121.70 \text{ Mols/Hr}$$

$$W_A = 1.56 \text{ Mols/Hr}$$

Enthalpy

At 114.7 PSIA and -272°F

$$H_3 = 95.79 \text{ Btu/Lb}$$

Point 4-N High Pressure Air Leaving Air Liquifier

Pressure 114.7 PSIA

Temperature -272°F

Fluid State

The liquid requirement of the air entering the liquifier is the
sum of the liquid equivalent of the product takeoff, the liquid

equivalent of the heat loss, and the liquid equivalent of the expansion loss.

Product Liquid Equivalent

The latent heat of nitrogen at 52.2 PSIA is $H = 78.00 \text{ Btu/Lb}$

On the basis of 4.3% recovery

$$H = 3.35 \text{ Btu/Lb}$$

Heat Loss Liquid Equivalent

$$H_{H.L.} = 1.5 \text{ Btu/Lb}$$

Expansion Loss Liquid Equivalent

The enthalpy drop at saturated vapor conditions resulting from the expansion of incoming air from 114.7 PSIA to 21 PSIA is

$$H_{Exp} = 95.79 - 90.93$$

= 4.86 Btu/Lb Since only 25% of the incoming air is to be expanded

$$H_{Exp} = 0.25 \times 4.86$$

$$H_{Exp} = 1.22 \text{ Btu/Lb}$$

The total liquid requirement enthalpy drop is

$$H = H_{T.O.} + H_{H.L.} + H_{Exp}$$

$$= 3.35 + 1.50 + 1.22$$

$$= 6.07 \text{ Btu/Lb}$$

The latent heat of vaporization of air at 114.7 PSIA

$$L.H. = 95.79 - 22.61$$

$$= 73.18 \text{ Btu/Lb}$$

$$\text{Liquid Requirement} = H/L.H. \times 100$$

$$\text{Liquid Requirement} = 6.07/73.18 \times 100$$

$$= 8.29\%$$

Hence the fluid state will be 8.29% liquid and 91.71% vapor

Composition

Same as Point 3

$$W_{O_2} = 32.76 \text{ Mols/Hr}$$

$$W_{N_2} = 121.70 \text{ Mols/Hr}$$

$$W_A = 1.56 \text{ Mols/Hr}$$

Enthalpy

At 114.7 PSIA and -272°F

$$H_4 = 89.72 \text{ Btu/Lb}$$

Point 5-N High Pressure Air Leaving the Phase Separator and Entering the Expansion Valve

Entering the 7.8 atmosphere equilibrium curve for oxygen and nitrogen at -272° or 104.3% for 21 mol percent oxygen

$$\text{Total Mols} = \text{Mols Liquid} + \text{Mols Vapor}$$

$$0.21 = 0.0829 (0.366) + 0.9171 (0.196)$$

$$0.21 = 0.0303 + 0.1798$$

$$0.21 = 0.2101$$

$$\text{Mols Oxygen Vapor} = 0.1798 \times 156.02$$

$$W_{O_2} = 28.04 \text{ Mols/Hr}$$

$$\text{Mols Oxygen Liquid} = 0.0303 \times 156.02$$

$$W_{O_2} = 4.72 \text{ Mols/Hr}$$

The amount of air entering the phase separator which is expanded into the high pressure column through the Al expansion valves is

$$100 - 75 - 8.29 = 16.71\text{s}$$

Pressure

114.7 PSIA

Temperature

-272°F

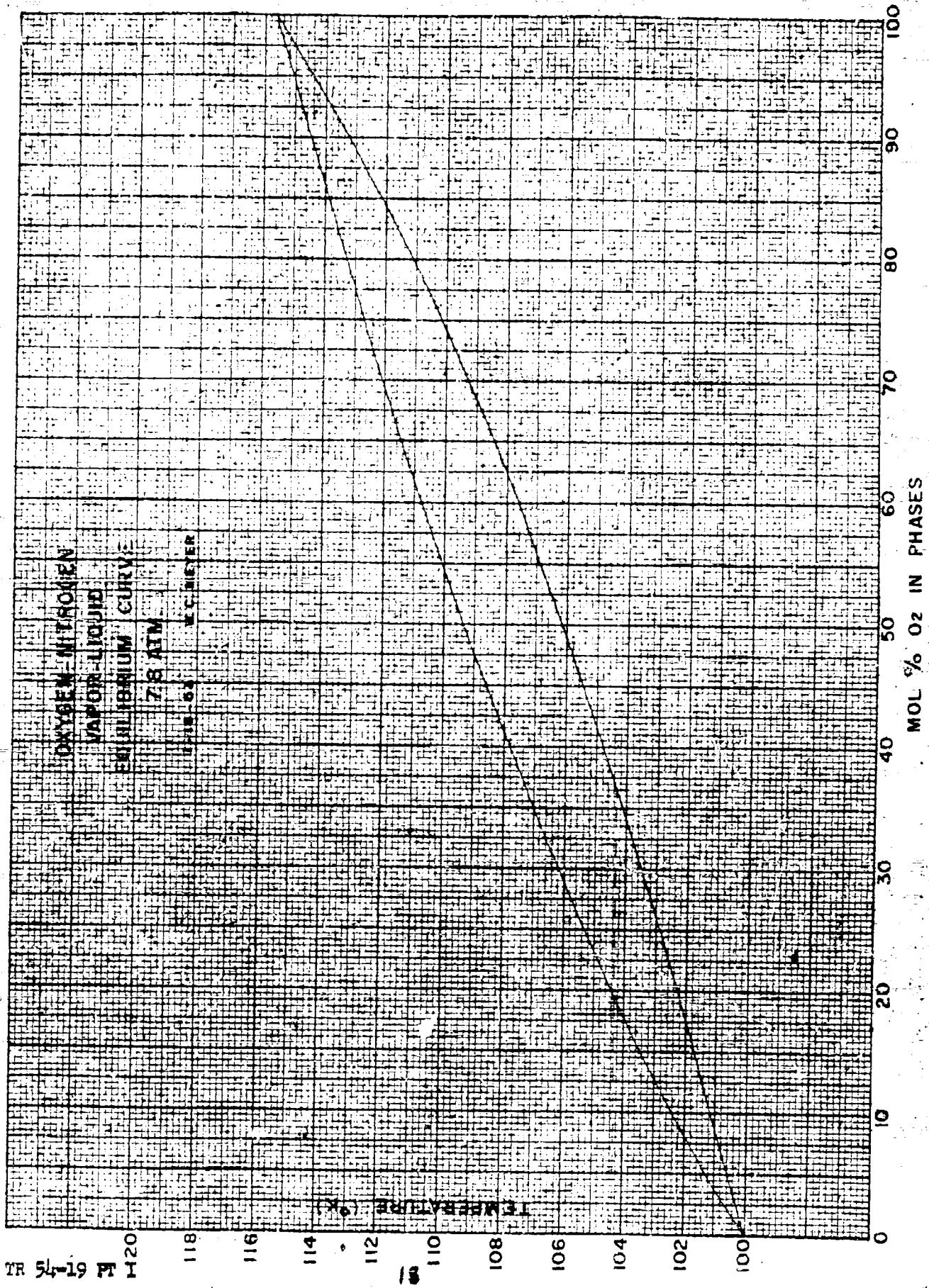
Fluid State

Saturated Vapor

Fluid Flow Rate

$$W_5 = 0.1671 \times 156.02$$

$$= 26.07 \text{ Mols/Hr}$$



114-116
110-112
104-106
102-104
100-102
98-100
96-98
94-96
92-94
90-92
88-90
86-88
84-86
82-84
80-82
78-80
76-78
74-76
72-74
70-72
68-70
66-68
64-66
62-64
60-62
58-60
56-58
54-56
52-54
50-52
48-50
46-48
44-46
42-44
40-42
38-40
36-38
34-36
32-34
30-32
28-30
26-28
24-26
22-24
20-22
18-20
16-18
14-16
12-14
10-12
8-10
6-8
4-6
2-4
0-2

Composition

$$W_{O_2} = 26.07 \times 0.196$$

$$= 5.11 \text{ Mols/Hr}$$

$$W_A = 1/21 \times 5.11$$

$$= 0.24$$

$$W_{N_2} = 26.07 - 5.11 - 0.24$$

$$= 20.72 \text{ Mols/Hr}$$

Enthalpy

At 114.7 PSIA and -272°F

$$H_5 = 95.79 \text{ Btu/Lb}$$

Point 6-N High Pressure Air Entering High Pressure Nitrogen Column

Pressure 52.2 PSIA

Temperature -282.5°F

Fluid State Superheated Vapor

Fluid Flow Rate Same as Point 5

$$W_6 = 26.07 \text{ Mols/Hr}$$

Composition Same as Point 5

$$W_{O_2} = 5.11 \text{ Mols/Hr}$$

$$W_{N_2} = 20.72 \text{ Mols/Hr}$$

$$W_A = 0.24 \text{ Mols/Hr}$$

Enthalpy

At 52.2 PSIA and -282.5°F

$$H_6 = 95.79 \text{ Btu/Lb}$$

Point 7-N High Pressure Air Leaving Phase Separator and Entering Cold Heat Exchanger

The pressure and temperature are the same as Point 5 with the flow and composition proportional to the division of the total vapor phase leaving the phase separator.

Pressure	114.7 PSIA
Temperature	-272°F
Fluid State	Saturated Vapor
Fluid Flow Rate	

$$W_7 = 0.75 \times 156.02$$

$$= 117.02 \text{ Mols/Hr}$$

Composition

W_{O_2} = Total O₂ Vapor leaving separator - Oxygen to Column

$$W_{O_2} = 28.04 - 5.11$$

$$= 22.93 \text{ Mols/Hr}$$

$$W_A = 1/21 \times 22.93$$

$$= 1.09 \text{ Mols/Hr}$$

$$W_{N_2} = 117.02 - 1.09 - 22.93$$

$$= 93.00 \text{ Mols/Hr}$$

Enthalpy

At 114.7 PSIA and -272°F

$$H_7 = 95.79 \text{ Btu/Lb}$$

Point 8-N High Pressure Air Entering Turbo Expander

Stream 7 in passing through the heat exchanger will undergo a slight pressure drop and rise in temperature. This warm-up will increase the expander efficiency.

Pressure	112 PSIA
Temperature	-240°F
Fluid State	Superheated Vapor
Fluid Flow Rate	Same as Point 7
W_8	= 117.02 Mols/Hr
Composition	Same as Point 7

$$W_{O_2} = 22.93 \text{ Mols/Hr}$$

$$W_{N_2} = 93.00 \text{ Mols/Hr}$$

$$W_A = 1.09 \text{ Mols/Hr}$$

Enthalpy

At 112 PSIA and -240°F

$$H_g = 104.50 \text{ Btu/Lb}$$

Point 9-N Low Pressure Air Leaving the Expander and Feeding the Low Pressure Column

No flow is demanded through Point 9 since the only purpose of such a flow is to give advantage to the low pressure column in so far as oxygen production is concerned.

Point 10-N Expander Exhaust Stream into Air Liquifier

Pressure 21 PSIA

Temperature -306°F

Fluid State Saturated Vapor

Fluid Flow Rate Same as Point 8

$$W_{10} = 117.02 \text{ Mols/Hr}$$

Composition Same as Point 8

$$W_{O_2} = 22.93 \text{ Mols/Hr}$$

$$W_{N_2} = 93.00 \text{ Mols/Hr}$$

$$W_A = 1.09 \text{ Mols/Hr}$$

Enthalpy 90.93 Btu/lb

Point 11-N Air Stream Feeding Air Liquifier

Pressure 21 PSIA

Temperature -306°F

Fluid State Saturated Vapor

Fluid Flow Rate

The flow will be stream 4 minus the product take-off

$$W_{11} = 156.02 - 2 \times 2000/0.86 \times 28 \times 24$$

$$W_{11} = 149.10 \text{ Mols/Hr}$$

Composition

Referring to compositions at Point 14, Point 6 and Point 10.

$$W_{O_2} = 5.11 + 4.72 + 22.93 - 0.04$$

$$= 32.72 \text{ Mols/Hr}$$

$$W_{N_2} = 20.72 + 7.99 + 93.00 - 6.84$$

$$= 114.87 \text{ Mols/Hr}$$

$$W_A = 0.24 + 0.22 + 1.09 - 0.04$$

$$= 1.51 \text{ Mols/Hr}$$

Enthalpy

Combination of Points 19 and 10

$$= \frac{90.93 \times 117.02 + 91.10 \times 32.08}{149.10} = 90.97 \text{ Btu/Lb}$$

Point 12-N Air Leaving Air Liquifier and Entering Cold Heat Exchanger

Pressure

19 PSIA

Temperature

All of the latent heat of the liquified air is taken by this stream.

$$(95.79 - 89.72) 156.02/149.10 = 6.34$$

$$6.34 + 90.97 = 97.31 \text{ Btu/Lb}$$

$$T_{12} = -283.6^\circ\text{F}$$

Fluid State

Superheated Vapor

Fluid Flow Rate

Same as Point 11

$$W_{12} = 149.10 \text{ Mols/Hr}$$

Composition

Same as Point 11

$$W_{O_2} = 32.72 \text{ Mols/Hr}$$

$$W_{N_2} = 114.87 \text{ Mols/Hr}$$

$$W_A = 1.51 \text{ Mols/Hr}$$

Enthalpy

At 19 PSIA and -283.6°F the enthalpy is

$$H_{12} = 97.31 \text{ Btu/Lb}$$

Point 13-N Waste Air Leaving Warm Heat Exchanger

Pressure

14.7 PSIA

Temperature

72°F

Fluid State

Superheated Vapor

Fluid Flow Rate

Same as Point 12

$$W_{13} = 149.10 \text{ Mols/Hr}$$

Composition

Same as Point 12

$$W_{O_2} = 32.72 \text{ Mols/Hr}$$

$$W_{N_2} = 114.87 \text{ Mols/Hr}$$

$$W_A = 1.51 \text{ Mols/Hr}$$

Enthalpy

At 14.7 PSIA and 72°F

$$H_{13} = 182.97 \text{ Btu/Lb}$$

Point 14-N High Pressure Liquid Leaving Phase Separator

Pressure

114.7 PSIA

Temperature

-275.6°F

Fluid State

Saturated Liquid

Fluid Flow Rate

$$W_{14} = 0.0829 \times 156.02$$

$$= 12.93 \text{ Mols/Hr}$$

Composition

$$W_{O_2} = 4.72 \text{ Mols/Hr}$$

$$W_A = 4.72 \times 1/21$$

$$W_A = 0.22 \text{ Mols/Hr}$$

$$W_{N_2} = 12.93 - 0.22 = 4.72$$

$$W_{N_2} = 7.99 \text{ Mols/Hr}$$

Enthalpy

At 114.7 PSIA and -275.6°F

$$H_{14} = 22.55 \text{ Btu/Lb}$$

Point 15-N Low Pressure Air Leaving Expansion Valve and Entering Low Pressure Column

The liquid air is expanded to the pressure at the top of the low pressure column at constant enthalpy.

Pressure

21. PSIA

Temperature

-304.3°F

Fluid State

The expansion of saturated liquid from 114.7 PSIA to 21 PSIA results in

79.05% Liquid

20.95% Vapor

Fluid Flow Rate

Same as Point 14

$$W_{15} = 12.93 \text{ Mols/Hr}$$

Composition

$$W_{O_2} = 4.72 \text{ Mols/Hr}$$

$$W_{N_2} = 7.99 \text{ Mols/Hr}$$

$$W_A = 0.22$$

Enthalpy

At 21 PSIA and -304.3°F

$$H_{15} = 22.55 \text{ Btu/lb}$$

Point 16 Liquid Air leaving High Pressure Column

This is the result of liquification of Stream 6 minus the product take-off.

Pressure	52.2 PSIA
Temperature	-291.9°F
Fluid State	Saturated Liquid

Fluid Flow Rate

$$W_{16} = 26.07 - 6.92 = 19.15 \text{ Mols/Hr}$$

Composition

$$W_{O_2} = 5.11 - 0.005 \times \frac{2000 \times 2}{24 \times 28 \times .86} = 5.07 \text{ Mols/Hr}$$

$$W_{N_2} = 20.72 - 6.84 = 13.88$$

$$W_A = 0.24 - 0.04 = 0.20$$

Enthalpy

At 52.2 PSIA and -291.9°F

$$H_{16} = 12.77 \text{ Btu/lb}$$

Point 17 Liquid Air Entering Low Pressure Column

Pressure	21 PSIA
Temperature	-304.3°F
Fluid State	Liquid and Vapor

The expansion of 52.2 PSIA saturated liquid to 21 PSIA results in 90.40% liquid and 9.60% vapor.

Fluid Flow Rate	Same as Point 16
-----------------	------------------

$$W_{17} = 19.15 \text{ Mols/Hr}$$

Composition	Same as Point 16
-------------	------------------

$$W_{O_2} = 5.07 \text{ Mols/Hr}$$

$$W_{N_2} = 13.88 \text{ Mols/Hr}$$

$$W_A = 0.20 \text{ Mols/Hr}$$

Enthalpy

At 21 PSIA and -304.3°F

$$H_{17} = 12.77 \text{ Btu/lb}$$

Point 18 Waste Air Leaving Low Pressure Column

The waste air leaving the low pressure column will be saturated vapor at the pressure at the top of the column.

Pressure	21.5 PSIA
Temperature	-304.3°F
Fluid State	Saturated Vapor
Fluid Flow Rate	

Stream 18 equals stream 19 which equals stream 4 minus stream 10 minus the product take-off

$$W_{18} = 156.02 - 117.02 - \frac{2 \times 2000}{24 \times 28} \times \frac{1}{0.84} \text{ (Due to product flash)}$$

$$W_{18} = 32.08 \text{ Mols/Hr}$$

Composition

Stream 15 / stream 17

$$W_{O_2} = 5.07 + 4.72 = 9.79 \text{ Mols/Hr}$$

$$W_{N_2} = 7.99 + 13.88 = 21.87 \text{ Mols/Hr}$$

$$W_A = 0.22 + 0.20 = 0.42 \text{ Mols/Hr}$$

Enthalpy

At 21 PSIA and -304.3°F

$$H_{18} = 91.10 \text{ Btu/lb}$$

Point 19-N Waste Air Leaving Subcooler (Same as Point 18)

Pressure	21 PSIA
Temperature	-304.3°F

Fluid State	Saturated Vapor
Fluid Flow Rate	Same as Point 18
$W_{19} = 32.08 \text{ Mols/Hr}$	
Composition	Same as Point 18
$W_{O_2} = 9.79 \text{ Mols/Hr}$	
$W_{N_2} = 21.87 \text{ Mols/Hr}$	
$W_A = 0.42 \text{ Mols/Hr}$	
Enthalpy	
As shown	
$H_{19} = 91.10 \text{ Btu/Lb}$	

Point 20 Liquid Nitrogen Entering Subcooler

Pressure	52.2 PSIA
Temperature	-298°F
Fluid State	Saturated Liquid
Fluid Flow Rate	
$W = \frac{2 \times 2000}{24 \times 0.86 \times 28}$	
$W_{20} = 6.92 \text{ Mols/Hr}$	
Composition	
$W_{N_2} = 6.92 \times 0.99 = 6.84 \text{ Mols/Hr}$	
$W_{O_2} = 0.04 \text{ Mols/Hr}$	
$W_A = 0.04 \text{ Mols/Hr}$	

It is assumed that the impurity is equally divided between oxygen and argon.

Enthalpy

At 52.2 PSIA and -298°F

$$H_{20} = 12.02 \text{ Btu/Lb}$$

Point 21-N Liquid Nitrogen Take-Off

Pressure	14.7 PSIA
Temperature	-298°F
Fluid State	14% Vapor 86% Liquid

Fluid Flow Rate

$$W_{21} = 6.92 \text{ Mols/Hr}$$

Composition

$$W_{N_2} = 6.84 \text{ Mols/Hr}$$

$$W_{O_2} = 0.04 \text{ Mols/Hr}$$

$$W_A = 0.04 \text{ Mols/Hr}$$

Vapor

$$W = 0.97 \text{ Mols/Hr}$$

Liquid

$$W = 5.95 \text{ Mols/Hr}$$

Enthalpy

At 14.7 PSIA and -298°F

$$H = 12.02 \text{ Btu/Lb}$$

Summary

The conditions calculated for the various points in the flow diagram are summarized below.

Pt.No.	Pressure (PSIA)	Temp. (°F)	Composition (Lb Mols/Hr)				Euthalpy Btu/Lb	Total Heat Btu/Hr
			O ₂	N ₂	A	Total		
1-N	14.7	70	33.84	125.71	1.61	161.16	Vapor	182.74
2-N	114.7	80	32.76	121.70	1.56	156.02	Vapor	184.30
3-N	114.7	-272	32.76	121.70	1.56	156.02	Vapor	95.79
4-N	114.7	-272	32.76	121.70	1.56	156.02	Liq&Vap	89.72
5-N	114.7	-272	5.11	20.72	0.24	26.07	Vapor	95.79
6-N	52.2	-282.5	5.11	20.72	0.24	26.07	Vapor	95.79
7-N	114.7	-272	22.93	93.00	1.09	117.02	Vapor	95.79
8-N	112.0	-240	22.93	93.00	1.09	117.02	Vapor	104.50
10-N	21.0	-306	22.93	93.00	1.09	117.02	Vapor	90.93
11-N	21.0	-306	32.72	114.87	1.51	149.10	Vapor	90.97
12-N	19.0	-283.6	32.72	114.87	1.51	149.10	Vapor	97.31
13-N	14.7	72	32.72	114.87	1.51	149.10	Vapor	182.97
14-N	114.7	-275.6	4.72	7.99	0.22	12.93	Liquid	22.55
15-N	21.5	-304.3	4.72	7.99	0.22	12.93	Liq&Vap	22.55
16	52.2	-292.9	5.07	13.88	0.20	19.15	Liquid	12.77
17	21.5	-304.3	5.07	13.88	0.20	19.15	Liq&Vap	12.77
18	21.5	-304.3	9.79	21.87	0.42	32.08	Vapor	91.10
19-N	21.0	-304.3	9.79	21.87	0.42	32.08	Vapor	91.10
20	52.2	-298	0.04	6.84	0.04	6.92	Liquid	12.02
21-N	14.7	-298	0.04	6.84	0.04	6.92	Liq&Vap	12.02

Heat Balance

For any heat balance $Q_{in} = Q_{out}$ where $Q = W(\text{lbs/Hr}) \times H(\text{Btu/lb})$

Heat Exchanger Balance

$Q_{in} = Q_2 + Q_7 + Q_{12}$ where Q_2 is corrected to allow for the loss due to reversal

$$= 831,005 + 323,950 + 419,914$$

$$= 1,574,869$$

$$Q_{out} = Q_3 + Q_8 + Q_{13}$$

$$= 431,915 + 353,406 + 789,548$$

$$= 1,574,869$$

Air Liquifier Balance

$$Q_{in} = Q_3 + Q_{11}$$

$$= 431,915 + 392,545$$

$$= 824,460$$

$$Q_{out} = Q_4 + Q_{12}$$

$$= 404,546 + 419,914$$

$$= 824,460$$

Phase Separator Heat Balance

$$Q_{in} = Q_4$$

$$= 404,546$$

$$Q_{out} = Q_5 + Q_7 + Q_{14}$$

$$= 72,170 + 323,950 + 8,426$$

$$= 404,546$$

Turbo Expander Heat Balance

$$Q_{in} = Q_g$$

$$= 353,406$$

$$Q_{out} = Q_{10} + Q_{work}$$

$$= 307,514 + Q_w$$

$$Q_{work} = 353,406 - 307,514$$

$$= 45,892$$

or

$$= 18.04 \text{ H.P.}$$

Distillation Column Heat Balance

$$Q_{in} = Q_6 + Q_{15} + Q_{\text{Heat Leak}}$$

$$= 72,170 + 8,426 + (156.02 \times 1.5 \times 28.9)$$

$$= 87,360$$

$$Q_{out} = Q_{18} + Q_{20}$$

$$= 85,031 + 2,329$$

$$= 87,360$$

Overall Heat Balance

Liquid Oxygen Production

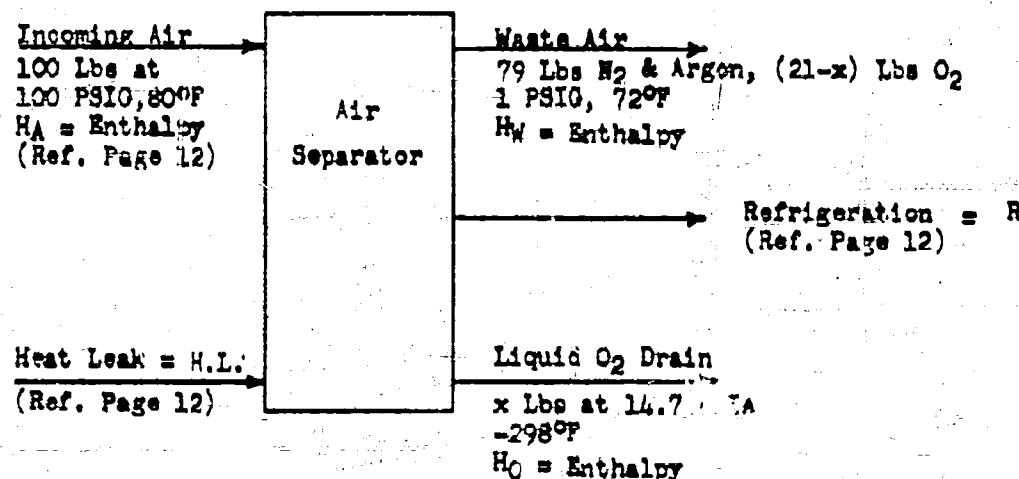


Figure 8 Liquid Oxygen Generator Heat Balance

Enthalpy of the Liquid O_2 Drained, H_O

At the conditions of 14.7 PSIA and -298°F the enthalpy of the liquid O_2 is

$$H_O = 8.89 \text{ Btu/Lb}$$

For x Lbs. drained

$$H_O = 8.89x \text{ Btu}$$

Enthalpy of the Effluent Waste Air, H_W

At the conditions of 1 PSIG and 72°F the enthalpy of the waste air is equal to the sum of the enthalpies of the constituents.

The enthalpy of nitrogen at these conditions is

$$H_{NW} = 183.5 \text{ Btu/Lb}$$

All of the nitrogen contained in the intake air will be waste thus

$$H_{NW} = 183.5 \times 79 = 14,497 \text{ Btu}$$

The enthalpy of oxygen at these conditions is

$$H_{OW} = 181.2 \text{ Btu/Lb}$$

The oxygen contained in the waste air will be

$$(21 - x) \text{ Lbs}/100 \text{ Lbs of Air Feed}$$

$$H_{OW} = 181.2 (21 - x)$$

$$= 3805 = 181.2x \text{ Btu}$$

$$H_W = H_{NW} + H_{OW} = 14,497 + 3,805 = 181.2x$$

$$H_W = 18,302 = 181.2x \text{ Btu}$$

Total Heat Balance

The total heat balance will be

$$H_A + H.L. = H_W + R + H_O$$

$$18,430 + 150 = 18,302 - 181.2x + 1,018 + 8.89x$$

$$740 = 172.31x$$

$$x = 4.29 \text{ Lbs O}_2/100 \text{ Lbs Air Feed}$$

This indicates a 4.29% recovery by weight. For two tons per day the required air intake will be

$$Q = 2 \frac{\text{Tons}}{\text{Days}} \times \frac{2000 \text{ Lbs}}{1 \text{ Ton}} \times \frac{1 \text{ Days}}{24 \text{ Hr}} \times \frac{1 \text{ Hrs}}{60 \text{ Min}} \times \frac{1 \text{ Cu Ft}}{0.075 \text{ Lb}} \times \frac{1}{0.0429}$$

$$Q = 863 \text{ SCFM}$$

Assuming a 3% loss during reversal

$$0.03 \times 863 = 25.9$$

$$Q = 863 + 25.9 = 889 \text{ say } 890 \text{ SCFM}$$

Since the expander requires 750 SCFM and the compressors are capable of 1000 SCFM

$$Q = 1000$$

$$\frac{1000 \times 24 \times 60 \times 0.075 \times 0.0429}{2000}$$

$$\text{Production} = 2.32 \text{ T/D}$$

$$Q \text{ including Reversal Loss} = 1030 \text{ SCFM}$$

Summary: Liquid Oxygen Production

As in the liquid nitrogen cycle the following points are the result of the thermodynamic analysis:

Pt. No.	Pressure (PSIA)	Temp. (°F)	Composition (lb Mols/Hr)				Phase	Enthalpy Btu/lb	Total Heat Btu/Hr
			O ₂	N ₂	A	Total			
*1-0	14.7	70	32.70	121.45	1.56	155.71	Vapor	182.74	822,333
2-0	114.7	80	32.70	121.45	1.56	155.71	Vapor	184.30	829,354
3-0	114.7	-272	32.70	121.45	1.56	155.71	Vapor	95.79	431,039
4-0	114.7	-272	32.70	121.45	1.56	155.71	Liq&Vap	89.22	401,492
5-0	114.7	-272	4.86	19.85	0.23	24.94	Vapor	95.79	69,095
22	89	-276	4.86	19.85	0.23	24.94	Vapor	95.79	69,095
7-0	114.7	-272	22.77	92.93	1.08	116.78	Vapor	95.79	323,286
8-0	112.0	-240	22.77	92.93	1.08	116.78	Vapor	104.5	352,681
10-0	21	-306	22.77	92.93	1.08	116.78	Vapor	90.93	306,883
11-0	21	-305	26.69	121.45	1.53	149.67	Vapor	90.56	390,149
12-0	19	-281	26.69	121.45	1.53	149.67	Vapor	97.45	419,696
13-0	14.7	72	26.69	121.45	1.53	149.67	Vapor	182.97	788,598
14-0	114.7	-275.6	5.10	8.64	0.24	13.98	Liquid	22.55	9,111
15-0	21	-304.3	5.10	8.64	0.24	13.98	Liq&Vap	22.55	9,111
23	89	-282	4.86	19.85	0.23	24.94	Liquid	19.18	13,624
24	21	-304.3	4.86	19.85	0.23	24.94	Liq&Vap	19.18	13,824
25	21	-311.5	3.92	28.52	0.45	32.89	Vapor	86.96	82,757
19-0	21	-305.0	3.92	28.52	0.45	32.89	Vapor	87.48	83,248
26	21	-291	6.01	0.00	0.03	6.04	Liquid	11.43	2,209
21-0	14.7	-298	6.01	0.00	0.03	6.04	Liquid	8.89	1,712

NOTE: 3% Reversal Loss not included in Point 1 Tabulation

Overall Heat Balance

Gaseous Nitrogen Production

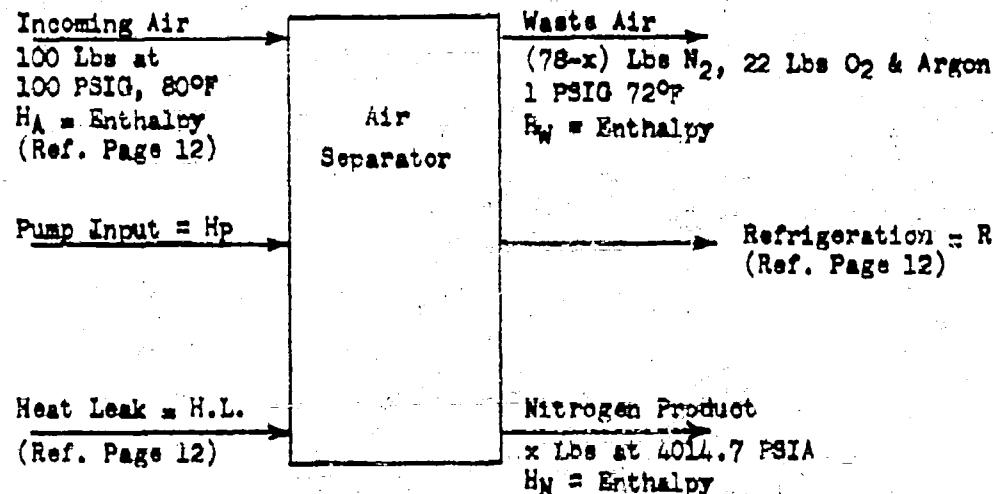


Figure 9 Gaseous Nitrogen Heat Balance

Enthalpy of the Liquid N_2 Pumped, H_N

At the condition of 4014.7 PSIA, the enthalpy of the pumped nitrogen is

$$H_N = 12.02 \text{ Btu/lb}$$

For x Lbs pumped

$$H_N = 12.02x \text{ Btu}$$

Enthalpy of the Effluent Waste Air, H_W

At the conditions of 1 PSIG and 72°F the enthalpy of the waste air is equal to the sum of the enthalpies of the constituents.

$$H_{WW} = 183.5 \text{ Btu/lb}$$

The nitrogen contained in the waste air will be $(78 - x)$ Lbs/100 Lbs of Air Feed thus

$$H_{WW} = (78 - x) 183.5$$

$$= 14,313 - 183.5x$$

The enthalpy of oxygen at these conditions is

$$H_{OW} = 181.2 \text{ Btu/lb}$$

All of the oxygen contained in the intake air will be waste hence

$$H_{OW} = 181.2 \times 22$$

$$= 3,986 \text{ Btu}$$

$$H_W = H_{NW} + H_{OW} = 14,313 - 183.5x + 3,986$$

$$H_W = 18,299 - 183.5x$$

Pump Input

It is estimated that the pump input to the circuit is 2 H.P. or

$$2 (\text{HP}) \times 2544 \frac{\text{Btu}}{(\text{I})} \times \frac{1}{(\text{HP-Hr})} \frac{(\text{Hrs})}{166.6} \frac{(\text{lb N}_2)}{\text{lb N}_2} = 30.53 \text{ Btu/lb N}_2$$

Since there are to be x lbs of nitrogen pumped per 100 lbs of air feed.

$$H_p = 30.53x \text{ Btu}$$

Total Heat Balance

The total heat balance will be

$$H_A + H.L. + H_p = H_W + R + H_N$$

$$18,430 + 150 + 30.53x = 18,299 - 183.5x + 1,018 + 12.02x$$

$$18,580 + 30.53x = 19,317 - 171.48x$$

$$202.01x = 737$$

$$x = 3.65 \text{ lbs N}_2/100 \text{ lbs Air Feed}$$

This indicates a 3.65% recovery by weight. For two tons per day the required air intake will be

$$Q = 2 \frac{\text{Tons}}{\text{Day}} \times \frac{2000}{1} \frac{\text{lbs}}{\text{Ton}} \times \frac{1}{24} \frac{\text{Days}}{\text{Hr}} \times \frac{1}{60} \frac{\text{Hrs}}{\text{Min}} \times \frac{1}{0.075} \frac{\text{Gal Ft}}{\text{lb}} \times \frac{1}{0.0365}$$

$$Q = 1045 \text{ SCFM}$$

Since 3% is assumed to be Reversal Loss

$$0.03 \times 1045 = 30$$

$$\text{Total Air Required} = 1045 \text{ S.C.F.M.}$$

Summary: Gaseous Nitrogen Production

As in the liquid nitrogen cycle the following points are the result of the thermodynamic analysis:

Pt. No	Pressure (PSIA)	Temp. (°F)	Composition (Lb Mols/Hr)				Phase	Enthalpy Btu/Lb	Total Heat Btu/Hr
			O ₂	N ₂	A	Total			
#1-PN	14.7	70	33.19	123.27	1.58	158.04	Vapor	182.74	859,355
2-PN	114.7	80	33.19	123.27	1.58	158.04	Vapor	184.30	841,764
3-PN	114.7	-272	33.19	123.27	1.58	158.04	Vapor	95.82	437,624
4-PN	114.7	-272	33.19	123.27	1.58	158.04	Liq&Vap	89.14	407,123
5-PN	114.7	-272	4.86	19.99	0.23	25.08	Vapor	95.82	69,451
6-PN	52.2	-282.5	4.86	19.99	0.23	25.08	Vapor	55.82	69,451
7-PN	114.7	-272	23.05	94.38	1.10	118.53	Vapor	95.82	328,268
8-PN	112.0	-240	23.05	94.38	1.10	118.53	Vapor	104.56	358,183
10-PN	21.0	-307	23.05	94.38	1.10	118.53	Vapor	90.80	311,070
11-PN	21.0	-306	33.16	117.38	1.55	152.09	Vapor	90.96	399,804
12-PN	19.0	-280	33.16	117.38	1.55	152.09	Vapor	97.90	430,305
13-PN	14.7	72	33.16	117.38	1.55	152.09	Vapor	183.04	804,530
14-PN	114.7	-275.6	5.27	8.91	0.25	14.43	Liquid	22.55	9,404
15-PN	21.0	-304.3	5.27	8.91	0.25	14.43	Liq&Vap	22.55	9,404
27	21.0	-304.3	5.27	8.91	0.25	14.43	Liq&Vap	34.75	14,492
16-PN	52.2	-291.9	4.83	14.10	0.20	19.13	Liquid	12.77	7,060
17-PN	21.0	-304.3	4.83	14.10	0.20	19.13	Liq&Vap	12.77	7,060
18-PN	21.0	-304.3	10.10	23.01	0.45	33.56	Vapor	91.49	89,734
20-PN	114.7	-298	0.03	5.89	0.03	5.95	Liquid	12.02	2,060
29	114.7	-298	0.03	5.89	0.03	5.95	Liquid	12.02	2,060
30	4014.7	-298	0.03	5.89	0.03	5.95	Vapor	12.02	2,060

NOTE: 3% Reversal Loss not included in Point 1 Tabulation

Overall Heat Balance

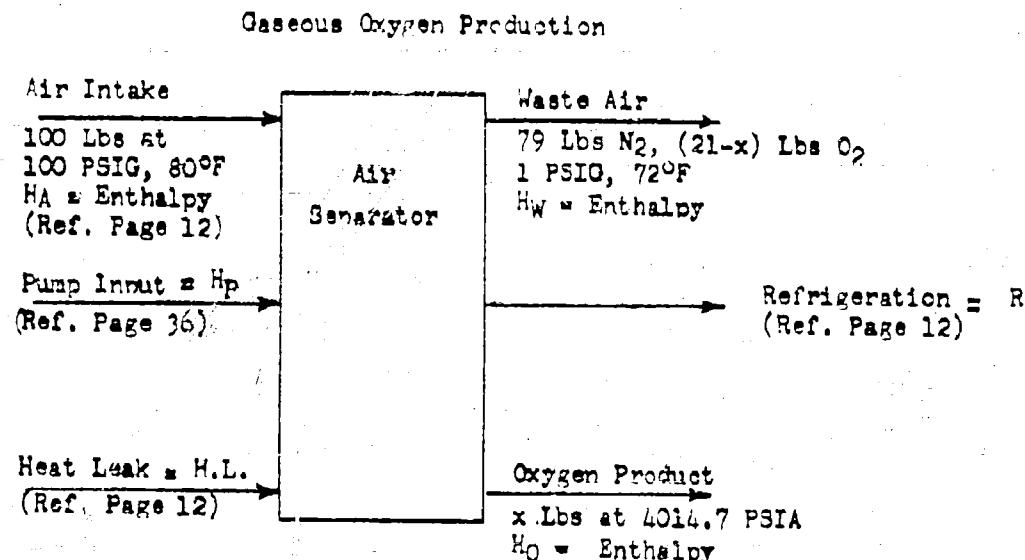


Figure 10 Gaseous Oxygen Heat Balance

Enthalpy of the Liquid O_2 Pumped, H_O

At the condition of 4014.7 PSIA the enthalpy of the pumped liquid is

$$H_O = 8.89 \text{ Btu/Lb}$$

For x Lbs. pumped

$$H_O = 8.89x \text{ Btu}$$

Enthalpy of the Effluent Waste Air, H_W

At the conditions of 72°F and 1 PSIG the enthalpy of the effluent waste air equals the sum of the enthalpies of the constituents.

The enthalpy of nitrogen under these conditions is

$$H_{NW} = 183.5 \text{ Btu/Lb}$$

All of the nitrogen contained in the intake air will be waste thus

$$H_{NW} = 183.5 \times 79 = 14,497 \text{ Btu}$$

The enthalpy of oxygen under these conditions is

$$H_{OW} = 181.2 \text{ Btu/Lb}$$

The oxygen contained in the waste air will be

$$(21 - x) \text{ Lbs}/100 \text{ Lbs of Air Feed hence}$$

$$H_{OW} = 181.2 (21 - x)$$

$$= 3,805 - 181.2x$$

$$H_W = H_{NW} + H_{OW} = 14,497 + 3,805 - 181.2x$$

$$H_W = 18,302 - 181.2x \text{ Btu}$$

Total Heat Balance

The total heat balance will be

$$H_A + H.L. + H_P = H_W + R + H_O$$

$$18,430 + 150 + 30.53x = 18,302 - 181.2x + 1,018 + 8.89x$$

$$740 = 203.74x$$

$$x = 3.63 \text{ Lbs O}_2/100 \text{ Lbs Air Feed or } \approx 3.63\% \text{ by weight recovery}$$

The required air intake for two tons per day will be

$$Q = 2 \frac{\text{Tons}}{\text{Day}} \times \frac{2000 \text{ Lbs}}{1 \text{ Ton}} \times \frac{1 \text{ Days}}{24 \text{ Hr}} \times \frac{1 \text{ Hrs}}{60 \text{ Min}} \times \frac{1 \text{ Cu Ft}}{0.075 \text{ Lb}} \times \frac{1}{0.0363}$$

$$= 1020 \text{ SCFM}$$

Assuming 3% Loss upon Reversal

$$Q = 1050 \text{ SCFM}$$

Summary: Gaseous Oxygen Production

As in the liquid nitrogen cycle the following points are the result of the thermodynamic analysis:

Pt. No	Pressure (PSIA)	Temp. (F°)	O ₂	N ₂	A	Composition (Lb Mole/Hr) Total	Phase	Enthalpy Btu, ₂₀	Total Heat Btu/Hr
*1-PO	14.7	70	33.35	123.88	1.59	158.82	Vapor	182.74	838,758
2-PO	114.7	80	33.35	123.88	1.59	158.82	Vapor	184.30	845,918
3-PO	114.7	-272	33.35	123.88	1.59	158.82	Vapor	95.79	439,666
4-PO	114.7	-272	33.35	123.88	1.59	158.82	Liq&Vap	88.11	404,433
5-PO	114.7	-272	4.43	18.40	0.21	23.04	Vapor	95.79	63,782
22-PO	89	-276	4.43	18.40	0.21	23.04	Vapor	95.79	63,782
7-PO	114.7	-272	22.89	95.14	1.09	119.12	Vapor	95.79	329,764
8-PO	112	-260	22.89	95.14	1.09	119.12	Vapor	104.50	359,748
10-PO	21	-306	22.89	95.14	1.09	119.12	Vapor	90.93	313,033
11-PO	21	-305	28.17	123.88	1.56	153.61	Vapor	90.02	398,193
12-PO	21	-281	28.17	123.88	1.56	153.61	Vapor	97.98	433,426
13-PO	14.7	72	28.17	123.88	1.56	153.61	Vapor	182.97	809,694
14-PO	114.7	-275.6	6.03	10.34	0.29	16.66	Liquid	22.55	10,887
15-PO	21	-304.3	6.03	10.34	0.29	16.66	Liq&Vap	22.55	10,887
28	21	-304.3	6.03	10.34	0.29	16.66	Liq&Vap	33.11	15,942
23-PO	89	-282	4.43	18.40	0.21	23.04	Liquid	19.18	12,771
24-PO	21	-304.3	4.43	18.40	0.21	23.04	Liq&Vap	19.18	12,771
25-PO	21	-311.5	5.28	28.74	0.47	34.49	Vapor	87.71	84,703
19-PO	21	-305	5.28	28.74	0.47	34.49	Vapor	88.14	85,127
26-PO	21	-291	5.18	0.00	0.03	5.21	Liquid	11.43	1,906
31	21	-298	5.18	0.00	0.03	5.21	Liquid	8.89	1,482
32	4014.7	-298	5.18	0.00	0.03	5.21	Vapor	8.89	1,482

NOTE: 3% Reversal Loss not included in Point 1 Tabulation

SECTION IV

EQUIPMENT SPECIFICATIONS

General

The equipment specifications listed below are considered to meet the requirements of the liquid oxygen, nitrogen generator from the viewpoints of performance, size, and weight. However, they shall be subject to possible changes resulting from final design considerations as well as availability of materials. The layout of the equipment components within a semitrailer is illustrated in Figure 12.

SEMITRAILER

Description

Semitrailer - The semitrailer shall be a Fruehauf semitrailer. It shall be constructed so that it is adaptable for towing by a standard Army truck tractor, and shall withstand the strains of service encountered when towed across the country with full equipment. The unit shall not exceed the following dimensions:

Height: 12 ft. 0 in.
Width: 9 ft. 6 in.
Length: 32 ft. 0 in.

The total weight of the semitrailer and equipment shall be approximately 45,756 pounds, of which approximately 16,450 pounds shall represent the weight of the semitrailer. The semitrailer shall permit a clear sweep of 70 inches behind the king pin for full turning. A standard SAE king pin shall be provided and shall be located approximately 22 inches back of the trailer front edge to permit the swinging of the trailer corner through a clear space of 62 inches. The trailer fifth wheel plate shall be of sufficient size to fit a 36-inch diameter fifth wheel on the truck tractor and shall be 53 inches from a level ground surface when the trailer floor is level.

Running Gear

Wheels - The wheels, studs and cap nuts shall conform to applicable Government specifications.

Wheel Hubs - The wheel hubs shall be fitted with tapered roller bearings of adequate size for the required speeds and loads. Bearings shall conform to SAE standards.

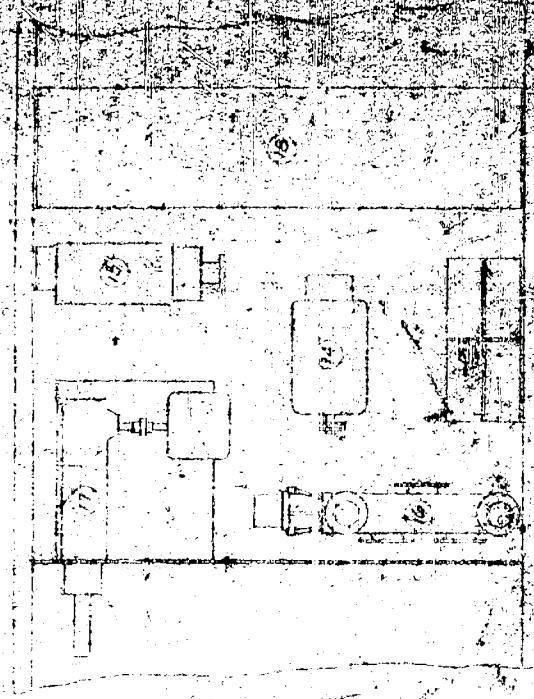
Tires - Tires shall be of the heavy duty, truck-and-bus, balloon type, with nondirectional mud-and-snow type tread.

Tubes - Tubes shall be of the heavy duty type.

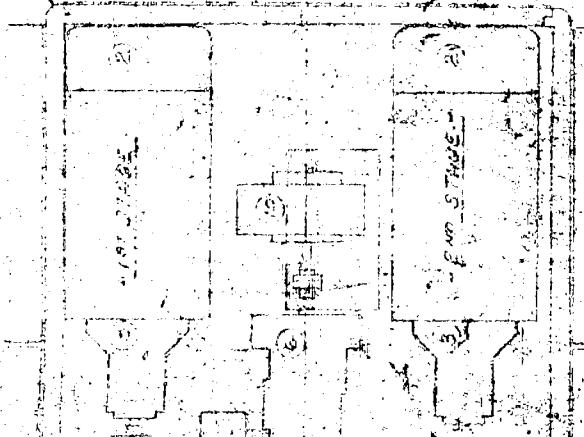
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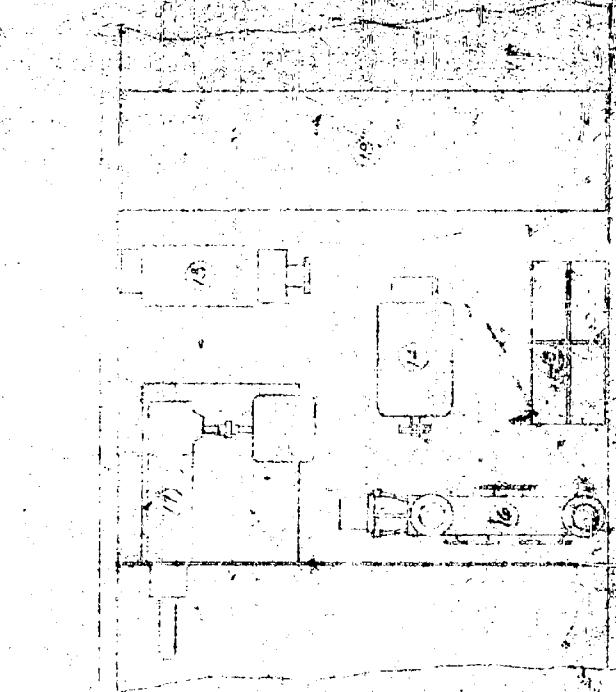
Mr. Blane ~



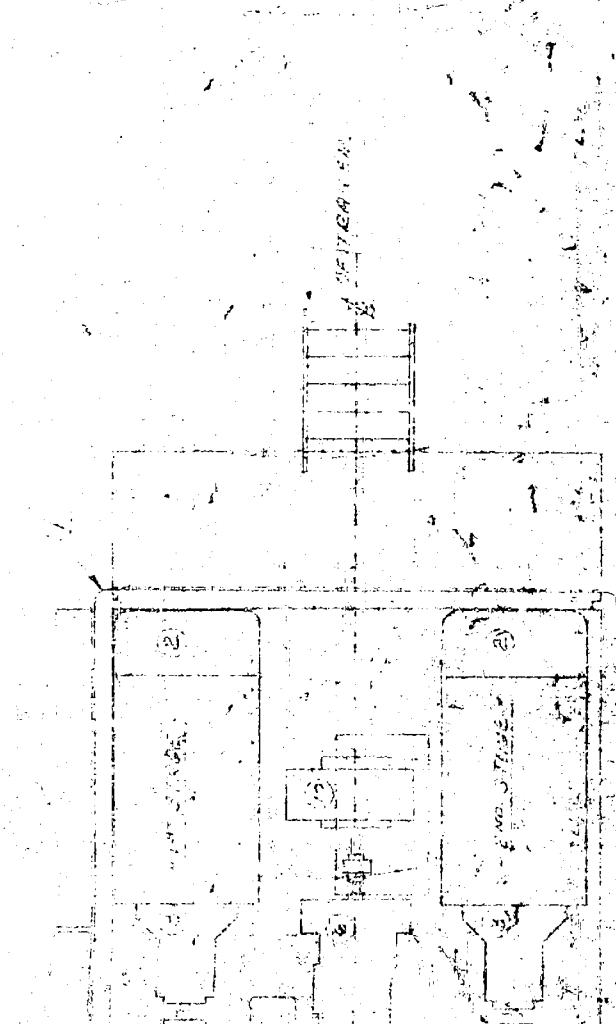


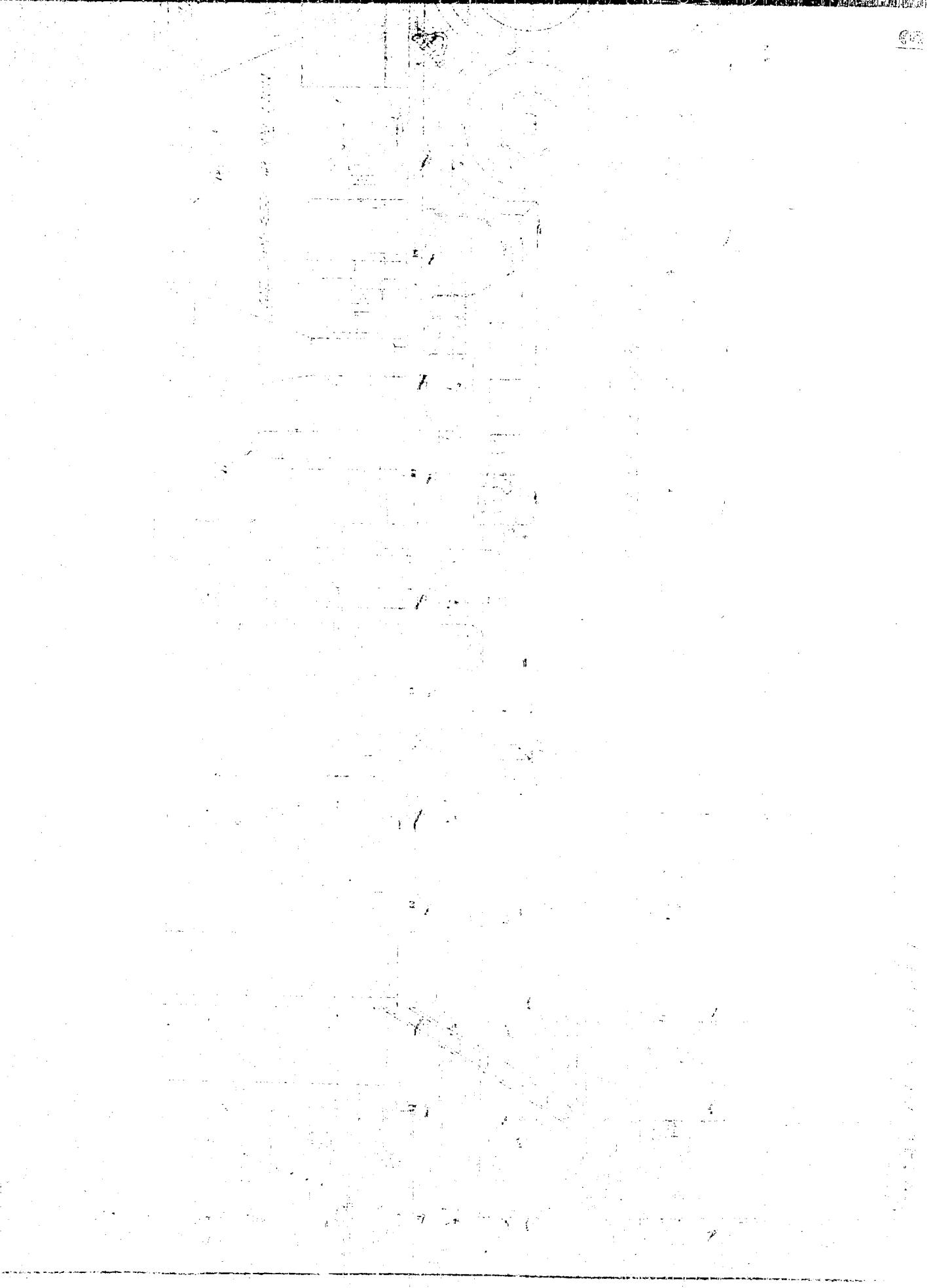
PLAN VIEW OF TRAILER 140' X 30'





PLAN OF THE ESTATE





Brakes

Service Brakes - Service brakes, controllable from the driver's seat of the towing vehicle, shall be provided. The drums shall have flanges or ribbing to prevent objectionable distortion when the brakes are applied. The brakes shall be of the internal expanding, two shoe, heavy-duty type, having constant lift cams and rigid brake-shoe anchors, and shall be operated through fully enclosed worm-gear type slack adjusters. Brakes, anchors, and cams shall have suitable lubrication fittings.

Service Brake Controls (Air) - All detail parts and assemblies of the brake control system shall be equal to and interchangeable with the equipment manufactured by The Bendix Westinghouse Automotive Air Brake Company, Elyria, Ohio, and shall be installed in accordance with the manufacturer's latest recommendations. The controls shall be provided with standard emergency break-away features. The break-away arrangement shall conform to requirements of the Interstate Commerce Commission. The controls shall be sealed in a manner that will ensure satisfactory operation in all kinds of weather. All chambers shall be provided with drains on the non-pressure side. Air hose connections and fittings shall be of the replaceable type with spring protectors. Air line filters shall be provided in both emergency and service lines. A relay emergency exhaust check valve and heavy-duty clamping studs shall be furnished. The standard air-brake couplings shall be provided for connecting the brake lines to the towing vehicle. A dummy coupling shall be attached with a chain to each of the air hose couplings. Two detachable air hose lines of proper length and equipped with standard air hose couplings, shall be supplied for connecting the brake system to the towing vehicle. When detached, the hose lines, with electrical connecting cable, shall be carried on the generating plant.

Parking Brakes - In addition to the air-brake mechanism, a ratchet-and-pawl type mechanism, or equivalent, shall be provided for operating and setting the brakes by hand. This brake shall be capable of skidding the wheels under full load on a dry, level, concrete pavement. The parking brakes shall be operated by a crank or lever placed in a suitable, protected position on the right hand side or rear of the vehicle. No part of the brake mechanism shall be a factor limiting the travel clearance.

Landing Gear - The landing gear shall be of rugged construction, shall be manually operated, and shall be so designed that the wheels may be independently operated to serve as leveling jacks. The landing gear shall be provided with a locking mechanism to lock the landing gear in any position. Two, built-in, screw-type leveling jacks shall be provided at the rear of the trailer. The jacks shall be dirt-proof and self-aligning. Suitable jack planks shall be furnished, conveniently mounted under the trailer.

Body - The body shall be of van-type with door and/or window openings designed to afford the most efficient operating conditions. The roof shall be crowned for drainage purposes, and shall be made in removable sections or provided with removable hatches to permit removal and replacement of equipment components within the van. The roofing material shall have sufficient strength to support a 200 pound man walking thereon. Suitable heavy-duty drip moulding shall be provided around the entire roof.

Floor - The semitrailer floor shall be adequate for the equipment loads and operating conditions. When an all metal floor is provided, it shall be coated with a suitable non-skid, plastic material. When a wood floor is provided, the wood for the floor shall be either maple or birch, second grade, in accordance with the National Maple Flooring Manufacturer's Association Grading Rules, or oak, select grade, in accordance with the National Oak Flooring Manufacturer's Association Grading Rules. Wood flooring shall be not less than $1\frac{1}{2}$ inches thick and shall be surfaced two sides and tongue-and-grooved. Floors shall be chemically treated to repel insects. Flooring shall run lengthwise of the trailer and shall be securely fastened to each cross member by means of galvanized wood screws with heads countersunk to be flush with the floor. The floor shall be sealed at all joints with pitch or other suitable sealing compound.

Doors and/or Windows - Doors, removable panels or hatches shall be provided on the semitrailer as required for convenience of operation, accessibility of plant components, and to facilitate removal of equipment for repair and maintenance. Windows shall be installed in the van-type body of the semitrailer as required. Windows shall be glazed with shatterproof glass.

Steps - Demountable-type steps shall be provided for use at the doors. Steps shall be provided with suitable grab handles and non-slip tread plates, and shall be easily attached and detached at the sill. Provision shall be made for storing steps inside the semitrailer when not in use.

Wiring - The vehicle shall be wired for an electrical supply of 24 volts direct current. Cable used for wiring shall be encased in flexible non-metallic tubing. Terminal lugs shall be soldered to the wire ends. Junction blocks shall have bases made of thermosetting, laminated, phenol-formaldehyde plastic, or other equally suitable material, and shall be equipped with suitable studs, washers and nuts for the attachment of terminal lugs. The circuits shall be color or number traced. Suitable grommets, or clamps, to prevent chafing of cable, shall be furnished where wire passes through structural members. A receptacle with hinged cover, to allow the running lights of the semitrailer to be controlled from the driver's seat of the towing vehicle, shall be recessed in the frame. A cable to connect the trailer to the towing vehicle shall be provided.

Lamps and Reflector Assemblies - All lamps shall be readily accessible for the changing of bulbs and lenses, and for making repairs. The stop and tail lamps shall be recessed approximately $\frac{1}{2}$ inch from the surface of the frame member. The following lamps and reflectors shall be provided on the vehicle, located to conform to Interstate Commerce Commission Motor Carrier Safety Regulations:

Reflector Reflector (Red and Amber)
Receptacle and Hinged Cover Assembly
R.H. Tail Lamp Assembly, 24 Volt
L.H. Tail Lamp Assembly, 24 Volt
Clearance Lamp Assembly, 24 Volt

Semitrailer Insulation - The semitrailer operating space shall be insulated with suitable insulating material such as mineral fiber bonded together with a thermosetting plastic resin to form a resilient, semi-rigid, dimensionally stable insulation, sealed in place against moisture infiltration.

Electrical Equipment - A suitable number of dome lights with necessary wiring and switches, and with bulbs of sufficient candlepower shall be installed to provide adequate light for operating the equipment at night. A sufficient number of convenience outlets shall be provided for emergency droplight cords. An emergency auxiliary lighting system supplied by power from the 24 volt diesel engine starting battery bank shall be provided.

Construction Design Methods - All construction design methods and materials for all parts of the unit shall be selected for the lightest possible end item without sacrifice of dependability and strength.

Lubrication - All moving parts shall be provided with suitable means of lubrication.

Lubricants - All moving parts shall be designed to operate efficiently and satisfactorily when lubricated with standard Armed Forces lubricants.

Grease Fittings - Grease fittings shall be located in accessible, protected positions. A bright red circle shall be painted around each lubricating point.

Caution Plates - Where the use of high-pressure lubricating equipment, 1,000 PSI or higher, will damage grease seals or other parts, a suitable warning shall be affixed to the equipment in a conspicuous location.

Fungus Control - The semitrailer shall be treated to resist the growth of fungus.

Lifting Attachments - The semitrailer shall be provided with suitable lifting attachments to enable the trailer, with all equipment installed in it, to be lifted in its normal position. The lifting attachment shall have a minimum safety factor of five based on the ultimate strength of the material. The eye of each lifting attachment shall be not less than three inches in diameter.

Manufacturer's Identification - The semitrailer shall bear the manufacturer's name and/or trademark on a name plate securely affixed in a conspicuous place. In lieu of the name plate, the manufacturer's identification may be cast integral with, stamped, or otherwise permanently marked upon the components of the equipment.

Instruction Plates - The semitrailer, when applicable, shall be equipped with instruction plates, suitably located, describing any special or important procedures to be followed in operating and servicing the equipment.

Treatment, Painting, and Stenciling - All parts of the semitrailer body and running gear shall be treated and painted to resist the effects of sand, dust, humidity and moist salt air.

Stenciling - The gross weight of the semitrailer with all equipment installed in it shall be stenciled on each side of the semitrailer in such manner as to be readily discernible to military personnel. The prescribed tire pressure shall be stenciled on the frame or body of the unit in a position near the wheels, using block- or stencil-type letters not more than one inch high.

AIR FILTER

Description

The air filter element shall be a Dollinger Corporation staynew Model WKE-4, dry panel type air filter, complete with cell frame and insert. The filtering medium shall be bonded glass. Two elements shall be required. They shall be mounted in a lightweight steel duct.

Specifications

Nominal Filter Element	
Size, Ins.	
Height	20
Width	25
Thickness	4
Normal Capacity	
Air Volume, CFM	750
Air Velocity, FPM	30
Maximum Capacity	
Air Volume, CFM	1000
Air Velocity, FPM	40
Active Filtering Area, Sq. Ft.	25
Pressure Drop	
At 750 CFM air Volume, Ins. of Water	0.02
At 1000 CFM Air Volume, Ins. of Water	0.04
Duct Size	
Height, Ins.	20
Width, Ins.	14
Length, Ins.	42
Approximate Total Weight, Lbs.	125

AIR COMPRESSOR

Description

The air compressor shall consist of three Read Standard Corporation "Standardaire" blowers. Each blower shall be a three lobe, rotary, positive displacement, axial flow, horizontal, heavy duty blower having helical rotors. By compounding one Model 8B14, one Model 7B10 and one Model 5B10 blower, 1000 standard cubic feet per minute of air shall be compressed from intake conditions of 14.7 PSIA and 70°F and discharged as oil-free air at 114.7 PSIA. Each blower shall be equipped with a shaft extension to provide a drive for an inter-cooler or aftercooler fan. This extension shall be capable of transmitting a load of 10 horsepower to the cooling fan by either a direct drive or through the use of a V-belt drive.

Each stage shall be tested individually in accordance with the American Society of Mechanical Engineers Power Test Code (PTC 9-39). Each stage shall be guaranteed to be within the permissible limit of 3% of the specifications listed below.

Specifications

	<u>1st Stage</u>	<u>2nd Stage</u>	<u>3rd Stage</u>
Blower Model	SB14	TB10	SB10
Speed, RPM	2330	2390	3220
Intake Pressure, PSIA	14.56	30.4	59.9
Discharge Pressure, PSIA	31.4	60.9	115.7
Absolute Pressure Ratio	2.16:1	2.0:1	1.93:1
Intake Volume, CFM	1100	556	277
Intake Temperature, °Rankine	530	560	560
Discharge Temperature, °F	264	302	287
Adiabatic Horsepower	60	56.5	52.3
Brake Horsepower	102	103	99
Overall Adiabatic Efficiency, %	59	55	53
Direction of Rotation, Viewing Driveshaft			
End	Clockwise	Clockwise	Clockwise
Approximate Size			
Length, In.	45-3/8	41	41
Width, In.	26-5/8	24-5/8	20-1/2
Height, In.	24-3/4	22-1/2	17-1/4
Approximate Weight, Lbs.	1227	950	710

INTERCOOLERS AND AFTERCOOLER

Description

The intercoolers and aftercooler shall be Trane Company coolers. They shall be of all aluminum construction. The cooling air face shall measure 20-5/8 inches by 32 inches, and the cooling air flow length shall be 10 inches.

Specifications

	<u>1st Stage Cooler</u>	<u>2nd Stage Cooler</u>	<u>3rd Stage Cooler</u>
Duty, Btu/Hr	235,000	270,000	235,000
Hot Air Side			
Flow, Lbs/Hr	4,500	4,500	4,500
Inlet Temperature, °F	264	302	287
Outlet Temperature, °F	90	90	90
Inlet Pressure, PSIG	16.7	46.7	101.0
Pressure Drop, PSI	0.49	0.30	0.22
H _L , Btu/Hr, Sq.Ft., °F	27.8	27.8	27.8
Number of Passages	24	24	24
Flow Length, In.	32	32	32
Fin Type	1/8 In. Serrated	1/8 In. Serrated	1/8 In. Serrated
Fin Height x Thickness, In.	0.375 x 0.006	0.375 x 0.006	0.375 x 0.006

1/ Sensible heat transfer coefficient corrected for fin efficiency.

	<u>1st Stage Cooler</u>	<u>2nd Stage Cooler</u>	<u>3rd Stage Cooler</u>
Fin Spacing, Per In.	12	12	12
Total Surface, Sq. Ft.	541	541	541
Air Inlet Connection Size, In.	6	4	3
Air Outlet Connection Size, In.	6	4	3
Air Blowdown Connection Size, In.	2	1-1/2	1-1/4
Cooling Air Side			
Flow, Lbs/Hr	13,500	13,500	13,500
Inlet Temperature, °F	80	80	80
Outlet Temperature, °F	152.3	163.1	152.3
Pressure Drop, In. Water	4.24	4.28	4.24
H, Btu/Hr., Sq. Ft., °F	22.9	22.9	22.9
Number of Passages	25	25	25
Flow Length, Ins.	10	10	10
Fin Type	Herringbone	Herringbone	Herringbone
Fin Height x Thickness, Ins.	0.416 x 0.006	0.416 x 0.006	0.416 x 0.006
Fin Spacing, Per In.	17	17	17
Total Surface, Sq. Ft.	850	850	850
Approximate Total Weight, Lbs.	120	120	120

INTER- AND AFTERCOOLER FANS

Description

The inter- and aftercooler fans shall be Trans Company centrifugal fans with the blades inclined backward to the direction of rotation. They shall be of single width and shall have single inlets. They shall be of lockseam-type construction, with convertible discharge orientation, and with standard steel shafts.

Specifications

	<u>1st Stage</u>	<u>2nd Stage</u>	<u>3rd Stage</u>
Fan Model	16 BI SWSI	16 BI SWSI	13 BI SWSI
Fan Size	16	16	13
Fan Arrangement	2	2	2
Fan Class	II	II	II
Wheel Width, %	85	85	95
Fan Speed, RPM	2350	2390	3280
Direction of Rotation Viewing Driveshaft End	Clockwise	Clockwise	Clockwise
Delivery, CPM	3465	3525	3465
Static Pressure, In. of Water	4.24	4.28	4.24
Brake Horsepower	3.28	3.42	3.69
Orientation of Discharge	Up Blast	Up Blast	Up Blast
Approximate Size			
Length, In.	28-3/4	28-3/4	26-1/8
Width, In.	31-3/4	31-3/4	26
Height, In.	33-3/8	33-3/8	27-5/8
Approximate Weight, Lbs.	86	86	70

DIESEL ENGINE

Diesel Engine Horsepower Requirements

In this generator, the blowers and inter- and aftercooler fans of each stage are direct-driven in tandem by separate diesel engines through suitable transmissions. In addition, a 18.7 Kva, 120/208 volt, 3 phase, 60 cycle electrical generator is belt driven by the third-stage diesel engine. The following table is a compilation of the anticipated brake horsepower loads on the individual diesel engines required to drive these components:

Stage	Brake Horsepower				Total
	Blower	Transmission Loss - 2 to 4%	Intercooler Fan	Electric Generator	
1st Stage	102	3.57	3.28		108.85
2nd Stage	103	3.60	3.42		110.02
3rd Stage	99	3.46	3.69	11.0	117.15

Description

The three diesel engines shall be General Motors Corporation two cycle, six cylinder, radiator-cooled, short base, open diesel engines, Series 6-71, Model 60300.

Specifications

Engine Model Number	60300
Engine	GM 6-71 PC55
Number of Cylinders	6
Bore, In.	4-1/4
Stroke, In.	5
Total Displacement, Cu. In.	425.6
Rated BHP, Basic Engine at 200 RPM	200
Rated BHP, with Standard Equipment at 1800 RPM	153
Continuous BHP, with Standard Equipment at 1800 RPM	138
Continuous BHP, with Standard Equipment at 1600 RPM	130
BMEP, Continuous Rating at 1800 RPM, PSI	71
BMEP, Continuous Rating at 1600 RPM, PSI	75
Maximum Torque, 1000 RPM (60 Cu. MM. Injector), Lb Ft	526
Piston Speed at 1800 RPM, FPM	1500
Piston Speed at 1600 RPM, FPM	1333
Compression Ratio	16:1
Lubrication	Forced Feed
Plywheel Housing Size	No. 1 SAE
Maximum Fuel Pump Lift to Fuel Pump Level, In.	48
Heat Absorbed by Cooling Water (Per HP at Ambient Temperature of 110°F) Btu/HP/Hr.	35
Air Required for Scavenging and Combustion at 1800 RPM, CFM	600
Exhaust Back Pressure (Maximum at Manifold Flange at 1800 RPM), In. Hg.	4
Lubricating Oil Refill Capacity, Including Filter(s), Qt.	29
Cooling Water System Capacity, Gal.	8-3/4

Approximate Size	
Length, In.	62-13/16
Width, In.	32
Height, In.	49-1/3
Approximate Weight, Dry, Lbs.	2600

Standard Equipment

Rotation - Counterclockwise, viewing flywheel end.

Cooling System - heavy duty radiator, lubricating oil cooler, water outlet manifold, thermostat for temperature control, engine water circulating pump, suction type fan.

Fuel System - Primary and secondary fuel filters, 60 cu. in. injectors, fuel circulating pump.

Lubrication System - Lubricating oil pressure pump, oil filter assembly.

Instruments - Instrument Panel Assembly includes: Starter switch, ammeter, lube oil pressure gauge, water temperature gauge, throttle control knob, remote control lever and space for accessory air heater controls and tachometer.

Miscellaneous - Fabricated steel base, hydraulic type governor with control on instrument panel, exhaust manifold and companion flange, tools for ordinary maintenance, manual for minor maintenance and operating instructions.

Optional Equipment

Electrical - Battery charging generator and voltage regulator assembly (24 volt, 600 watt insulated) starting motor (24 volt, insulated).

Miscellaneous - Air inlet housing for remotely mounted extra capacity air cleaner, Donaldson extra heavy duty oil bath type air cleaner.

Accessories

Automatic Bell Alarm for high water temperature and low oil pressure, air heater and pump for cold weather starting, 18-inch flexible exhaust connection with pipe thread ends, unmounted muffler for moderate silencing.

DIESEL ENGINE TRANSMISSION

Description

The diesel engine transmission shall be a Cotta Transmission Company Model FAAU-R Transmission equipped with an SAE No. 1 bell housing and Rockford single plates, 14", over-center clutch. It shall be complete with pilot bearings and oil circulating pump. The transmission shall be so designed and constructed, that it is capable of attachment and connection to a General Motors Model 60300 Series 6-71 RG55 Diesel Engine without modification. The transmission bell

housing shall be fabricated with a clutch operating shaft extending through and to the outside on both right and left hand sides of the bell housing to provide for optional location of a clutch operating lever.

Specifications

	<u>Unit No. 1</u> <u>1st Stage</u>	<u>Unit No. 2</u> <u>2nd Stage</u>	<u>Unit No. 3</u> <u>3rd Stage</u>
Horsepower to be Transmitted, Minimum	100	100	100
Input Speed, RPM (Approximate)	1580	1620	1600
Output Speed, RPM (Approximate)	2330	2390	3220
Overspeed Ratio	1.476:1	1.476:1	2.012
Transmission Efficiency, Per Cent	96 to 98	96 to 98	96 to 98
Type of Duty	Continuous	Continuous	Continuous
Direction of Rotation, Viewing	Counter-Clockwise	Counter-Clockwise	Counter-Clockwise
Approximate Size			
Length, In.	34	34	34
Width, In.	22	22	22
Height, In.	24	24	24
Approximate Weight, Lbs.	630	630	630

DIESEL ENGINE STARTING BATTERY

Description

The diesel engine starting battery shall be a Delco Products Division of General Motors Corporation Heavy Duty, Model 25A1, Six-Volt Storage Battery. The battery shall have three lead and acid type cells enclosed in a composition rubber case. Four of these batteries shall be connected in series to generate the 24 volts necessary to start the diesel engines.

Specifications

Capacity

200 Amphere Hours at 20 Hour Rating
150 Amphere Hours at 4 Hour Rating

Delivery Rates

50 Amperes for 175 Minutes at 80°F
300 Amperes for 11 Minutes at 0°F
820 Amperes for 1.5 Minutes at 0°F
1060 Amperes for 1.5 Minutes at 32°F

At the above rates the battery shall be depleted to an average of one volt per cell.

Approximate Size

Length, In.
Width, In.
Height, In.

16-1/2
7-1/2
10

Approximate Weight, Lbs.

80

DIESEL ENGINE FUEL OIL SUPPLY TANK

Calculation of Size

In accordance with the contract, the fuel supply tank shall have a minimum capacity for 12 hours of continuous operation for the generator at full load.

Specific Fuel Consumptions

First-Stage Engine at 108.85 BHP, 1600 RPM	7.14 GPH
Second-Stage Engine at 110.02 BHP, 1600 RPM	7.23 GPH
Third-Stage Engine at 117.15 BHP, 1600 RPM	7.68 GPH
Total	22.05 GPH

Capacity Required

$$V_{req'd} = 22.05 \frac{(\text{Gal})}{(\text{Hr})} \times 12 (\text{Hrs})$$

$$= 265 \text{ Gals.}$$

$$\text{Use } V_{\text{tank}} = 275 \text{ Gals.}$$

For the trailer which is 9 feet 6 inches wide, a steel, cylindrical fuel tank 8 feet 10 inches long shall be strapped beneath the floor of the air source section.

$$V_{\text{cyl}} = \pi \frac{D_1^2}{4} (\text{cross sectional area}) \times L (\text{length})$$

Also

$$V_{\text{cyl}} = 275 (\text{Gals}) \times 231 \frac{(\text{Cu In})}{(\text{Gal})}$$

$$D_1^2 = \frac{275 \times 231}{\pi \times 106} \times 4$$

$$D_1 = 27.68 \text{ Ins.} \quad \text{Use } 27.75 \text{ Ins.}$$

Specifications

Inside Diameter, In.	27.75
Length, In.	106.0
Thickness, In.	1/8
Capacity, Gals.	275
Weight, Dry, Lbs.	360
Weight, Wet, Lbs.	2310

AIR COMPRESSOR CONDENSATE TRAP

Description

The air compressor condensate trap shall be fabricated by Aif Products, Incorporated. It shall have a tangential side inlet and a bottom outlet. It shall have a condensate drain connection at the lowest point in the bottom head.

Specifications

Material	Steel
Shell Length, Ins.	30
Shell Diameter, Ins.	10
Shell Thickness, Ins.	1/8
Head Diameter, Ins.	10
Head Thickness, Ins.	1/8
Head Height, Ins.	4
Inlet Connection Size, Ins.	4
Outlet Connection Size, Ins.	4
Condensate Drain Connection Size, Ins.	1
Maximum Working Pressure, PSIG	100
Approximate Weight, Lbs.	50

SWITCH VALVE

Description

The switch valve shall be manufactured by Air Products, Incorporated. It shall be a double poppet-type valve having a carbon steel body and stainless steel stem. It shall have two 4-inch high pressure air inlet connections; one 5-inch waste air outlet connection; and two 5-inch connections common to both the high pressure air outlet and the waste air inlet. The switch valve shall be actuated by a Logansport Machine Company, Incorporated non-rotating, double-acting air cylinder, Model No. 2106C. The air cylinder shall have a 6-inch bore, 4-inch stroke and 1/2 inch iron pipe size air connections. The air cylinder, in turn, shall be controlled by a Bellows Company four-way solenoid air valve, Model No. EV-15B Electroaire Valve, having a 115/8 volt transformer and 1/2 inch iron pipe size air inlet connection. The solenoid valve shall be air powered and shall be actuated in both directions by low-voltage, momentary-energized solenoid coils. It shall have an operating pressure of 50 PSIG, and shall have adjustments provided to limit the speed of the control cylinder in both directions.

WARM HEAT EXCHANGER

Description

The warm heat exchanger shall be a Trane Company brazed aluminum core type heat exchanger.

Specifications

Core Size

17 in. passage width over channels
20-7/8 in. no flow (passage stack height)
88-1/2 in. core length over face channels

Core Passages

50 passages per core shall be headered into 2 streams of 25 passages each
16-1/2 in. width inside channels
0.375 in. nominal passage height

Fins

Trans 1/8 in. serrated
0.375 in. nominal height
15 fins per inch
0.008 in. thickness
81 in. effective heat transfer length

Distribution

Provision shall be made for gas distribution at each end of a passage.

Headers

The headers shall be fabricated from standard 5 inch 3SP aluminum pipe.

Shell

External parting sheets and 1/4 inch protective pads shall be provided on each core, one on each side of 20-7/8 inch no flow (passage stack height).

Supports

Support boxes and angles shall be provided at each end of the core.

Material Thickness, Inches

Outside Core Sheets	-	.064
Parting Sheets	-	.032
Side Channels	-	.040
Top Header Channels	-	.064
Side Protection Fin	-	.008
Packing Fin	-	.008
Distributor Fin	-	.024 Perforated

Tests

The core shall be subjected to hydrostatic and air pressure tests to check for interpassage and external leakage. The core shall be guaranteed to be satisfactory at a maximum working pressure of 100 PSIG.

COLD HEAT EXCHANGER

Description

The cold heat exchanger shall be a Trane Company brazed aluminum core type heat exchanger.

Specifications

Core Size

17 in. passage width over channels
20-7/8 in. no flow (passage stack height)
80-1/2 in. core length over face channels

Core Passages

50 passages per core shall be headered into 3 streams of 20, 20, and 10 passages respectively.
16-1/2 in. width inside channels
0.375 in. nominal passage height

Fins

Trane 1/8 in. serrated
0.375 in. nominal height
15 fins per inch
0.008 in. thickness
73 in. effective heat transfer length

Distribution

Provision shall be made for gas distribution at each end of a passage.

Headers

The headers shall be fabricated from standard 5 inch 3SP aluminum pipe.

Shell

External parting sheets and 1/16 inch protective pads shall be provided on each core, one on each side of 20-7/8 inch no flow (passage stack height).

Supports

Support boxes and angles shall be provided at each end of the cores.

Material Thickness, Inches

Outside Core Sheets	-	.064
Parting Sheets	-	.032
Side Channels	-	.040
Top Header Channels	-	.064
Side Protection Fin	-	.008
Packing Fin	-	.008
Distributor Fin	-	.024 Perforated

Tests

The core will be subjected to hydrostatic and air pressure tests to check for interpassage and external leakage. The core shall be guaranteed to be satisfactory at a maximum working pressure of 100 PSIG.

AIR LIQUEFYER

Description

The air liquefier shall be a Trane Company brazed aluminum core type heat exchanger.

Specifications

Core Size

8-3/4 in. passage width over channels
12-3/4 in. no flow (passage stack height)
51-1/4 in. core length over face channels

Core Passages

30 passages per core to be headered into 2 streams of 20 and 10 passages.
16-1/2 in. width inside channels
0.375 in. nominal passage height

Fins

Trane 1/8 in. serrated
0.375 in. nominal passage height
15 fins per inch
0.008 in. thickness
43-3/4 in. effective heat transfer length

Distribution

Provision shall be made for gas distribution at each end of a passage.

Headers

The headers shall be fabricated from standard 3 and 5 inch 3SF aluminum pipe.

Shells

External parting sheets and 1/4 inch protective pads shall be provided on each core, one on each side of 12-3/4 inch no flow (passage stack height).

Supports

Support boxes and angles shall be provided at each end of the core.

Material Thicknesses, Inches

Outside Core Sheets	- .064
Parting Sheets	- .032
Side Channels	- .040
Top Header Channels	- .064
Side Protection Fin	- .008
Packing Fin	- .008
Distributor Fin	- .024 Perforated

Tests

The core shall be subjected to hydrostatic and air pressure tests to check for interpassage and external leakage. The core shall be guaranteed satisfactory at a maximum working pressure of 100 PSIG.

CHECK VALVE

Description

The check valve shall be manufactured by Air Products, Incorporated. It shall be a double poppet-type valve of stainless steel construction. In one end it shall have one 4-inch high pressure air outlet connection; in the opposite end it shall have one 5-inch waste air inlet connection; and in the side it shall have one 5-inch connection common to both the incoming high pressure air and the effluent waste air. The check valve shall measure approximately 14 inches in length and shall weigh approximately 125 pounds.

PHASE SEPARATOR

Description

The phase separator shall be manufactured by Air Products, Incorporated. It shall be provided with a tangential, side, air inlet connection, a top vapor outlet connection, and a bottom liquid outlet connection. In addition, the phase separator shall be provided with connections to accommodate a liquid level gage.

Specifications

Model	41490D
Material	Copper
Shell Length, Ins.	24
Shell Diameter, Ins.	8-1/8 O.D.
Shell Thickness, Ins.	0.170
Head Diameter, Ins.	8-1/8 I.D.
Head Thickness, Ins.	1/4
Air Inlet Connection Size, Ins.	3-1/8 O.D.
Vapor Outlet Connection Size, Ins.	3-1/8 O.D.
Liquid Outlet Connection Size, Ins.	5/8 O.D.
Upper Liquid Level Gage Connection Size, Ins.	5/8 O.D.
Maximum Working Pressure, PSIG	100
Approximate Overall Length, Ins.	32
Approximate Weight, Lbs.	53

TURBO EXPANDER

Description

The turbo expander shall be an Air Products, Incorporated high-speed, centrifugal, expander, equipped with an air loaded energy absorber complete with lubrication system.

Specifications

The turbo expander shall be designed, built, and guaranteed to operate satisfactorily under the following conditions:

Fluid	Air
Flow Rate, Lb/Min	54.6
Inlet Pressure, PSIA	112
Exhaust Pressure, PSIA	21
Inlet Temperature, °F	-240
Exhaust Temperature, °F	-306
Approximate Weight, Lbs.	160

EXPANDER LOADER

Description

The expander loading device consists of a centrifugal impeller keyed to the expander shaft. The impeller rotates at the same speed as the expander wheel and imparts the shaft energy to the fluid being pumped. The amount of power which is absorbed is proportional to the quantity and density of the pumped fluid. This is controlled by a valve which admits the fluid to the inlet of the loader.

HYDROCARBON ADSORBER

Description

The hydrocarbon adsorber shall be an Air Products, Incorporated, silica gel type adsorber, Model No. 41510D. It shall consist of a pressure vessel having top inlet and bottom outlet connects. The pressure vessel shall be charged with silica gel. It shall be provided with filters to keep foreign particles from entering and silica gel from leaving the adsorber.

Specifications

Pressure Vessel	
Material	Copper
Shell Length, Ins.	36
Shell Diameter, Ins.	8-1/8 O.D.
Shell Thickness, Ins.	0.170
Head Diameter, Ins.	8-1/8 I.D.
Head Thickness, Ins.	1/4
Inlet Connection Size, Ins.	5/8 O.D.
Outlet Connection Size, Ins.	5/8 O.D.
Maximum Working Pressure, PSIG	15
Approximate Overall Length, Ins.	46
Approximate Weight, Charged, Lbs.	123

Adsorbent		Silica Gel
Material		3-8
Size, Mesh		38-40
Density, Lbs/Cu. Ft.		42
Quantity Required, Lbs.		
Inlet Filter		Porex Grade 1
Material		1-1/8 O.D.
Diameter, Ins.		1/8
Wall Thickness, Ins.		5-1/4
Length, Ins.		
Primary Outlet Filter		Alumina Tabular Balls
Material		1/4
Ball Diameter, Ins.		1/2
Quantity Required, Cu.Ft.		
Secondary Outlet Filter		Porex Grade 1
Material		1-1/8
Diameter, Ins.		1/8
Wall Thickness, Ins.		5-1/4
Length, Ins.		

OXYGEN DISTILLATION COLUMN

Description

The distillation column shall be an Air Products, Incorporated column. It shall consist of a tube-type condenser and a low pressure column having a number of bubble-cap pans of conventional design. The high pressure side of the condenser shall be designed and fabricated for a maximum working pressure of 100 PSIG. The low pressure column, which is also the low pressure side of the condenser, shall have a maximum working pressure of 15 PSIG. The column shall be provided with connections, properly sized and located, to accommodate all of the required column feeds and offtakes. Sufficient pans shall be included in the low pressure column to ensure that the product liquid oxygen, when withdrawn from the column at a rate of two tons per day, shall be 99.5% pure when the air available to the oxygen generator is approximately 1000 standard cubic feet per minute, and when the material balances are as calculated in Section III of this report. The column shall be approximately 13 1/8 inches in diameter and 8 feet 6 inches high and shall weigh approximately 600 pounds dry.

NITROGEN DISTILLATION COLUMN

Description

The distillation column shall be an Air Products, Incorporated column. It shall consist of a tube-type condenser and a high pressure column having a number of bubble-cap pans of conventional design. The high pressure column

and high pressure side of the condenser shall be designed and fabricated for a maximum working pressure of 100 PSIG. The low pressure column and low pressure side of the condenser shall be designed and fabricated for a maximum working pressure of 15 PSIG. The column shall be provided with the necessary connections, properly sized and located to accommodate all of the required column feeds and off-takes. Sufficient pans shall be included in the high pressure column to insure that the product liquid nitrogen when withdrawn from the column at a rate of two tons per day shall be 99.0% pure, when the air available to the generator is approximately 1000 standard cubic feet per minute and when the material balances are as calculated in Section III of this report. The column shall be approximately 13 1/8 inches in diameter and 5 feet 6 inches high and shall weigh approximately 450 pounds dry.

SUBCOOLER

Description

The subcooler shall be an Air Products, Incorporated extended-surface type heat exchanger, Model No. 41506C. In the subcooler, pure liquid shall flow through the tubes of the core while waste air gas shall flow around the tubes through the shell.

Specifications

Core

Material	Pinned Copper Tube
Tube Size, IPS	3/4
Tube Length, Ins.	60
Fin Height, Ins.	1/2
Fin Orientation	Axial
No. of Fins per Circumference	18
No. of Tubes	7
Liquid Inlet Connection Size, Ins.	7/8 C.D.
Liquid Outlet Connection Size, Ins.	7/8 O.D.
Maximum Working Pressure, PSIG	15

Shell

Material	Copper
Length, Ins.	75
Diameter, Ins.	6-1/8 O.D.
Thickness, Ins.	0.140
Head Diameter, Ins.	6-1/8 I.D.
Head Thickness, Ins.	0.187
Waste Air Inlet Connection Size, Ins.	3-1/8 O.D.
Waste Air Outlet Connection Size, Ins.	3-1/8 O.D.
Maximum Working Pressure, PSIG	15

Approximate Overall Length, Ins.

91

Approximate Weight, Lbs.

154

Liquid Product Pumps and Drive Motors

Description

The liquid product pumps shall be an Air Products, Incorporated horizontal, reciprocating-plunger type. The pumps shall be driven through a crank-and-connecting rod mechanism by electric motors through a gear reduction. The pumps shall be provided with thermal breaks which will allow the pump drive mechanisms to operate at atmospheric temperature while the pump cylinders are at the temperature of the liquid product being pumped. The pump capacities shall be controlled by variation of the pump stroke.

Specifications

Pump

Delivery, CFH gas Equivalent	2000
Plunger Diameter, Ins.	5/8
Stroke, Ins.	Variab le up to 3
Speed, RPM	100
Intake Pressure, PSIG	7
Discharge Pressure, PSIG	4000

Motors

3 Horsepower, 220/440 Volts, 3 Phase, 60 cycle, Squirrel-Cage Induction, Ball Bearing, Horizontal, Open, 40° Rise, Continuous Duty, Normal Torque, Low Starting Current, with 100 RPM American Gear Manufacturers' Association Class III, Helical Gears Hand Matched for Minimum Back Lash and Quiet Operation.

Oxygen-Nitrogen Vaporizer

Description

The oxygen-nitrogen vaporizer shall be manufactured by Air Products, Incorporated. It shall be a tube-type heat exchanger consisting of copper coils contained within a steel shell. The pure high pressure liquid product shall flow through the copper coils while high pressure air from the after-cooler of the air compressor shall flow across the tubes within the shell.

Specifications

Shell

Material	Steel
Length, Ins.	48
Diameter, Ins.	12
Thickness, Ins.	0.120
Head Diameter, Ins.	12
Head Thickness, Ins.	1/8
Maximum Working Pressure, PSIG	100

Cools		
Material		Cooper
Overall Coil Length, Ft.		450
Tube Diameter, Ins.		3/8 O.D.
Wall Thickness, Ins.		0.10
Maximum Working Pressure, PSIG		4000
Approximate Overall Length, Ins.	56	
Approximate Weight, Lbs.	270	

ALTERNATING-CURRENT GENERATOR

Specifications

The alternating-current generator shall have the following characteristics: 18.7 Kva, 120/208 volts, 3 phase, 4 wire, 60 cycle, .9 power factor, 1800 RPM, synchronous, horizontal, ball-bearing, drip-proof, self-excited by direct connected exciter, windings of generator and exciter shall be moisture and fungus proof.

The alternating-current generator shall have a shaft extension suitable for a V-belt drive and shall be complete with a solid adjustable base or slide rails.

HYDROCARBON ADSORBER REACTIVATION HEATER

Description

The hydrocarbon adsorber reactivation heater shall be an Air Products, Incorporated resistance heater, Model No. 31144C. It shall consist of two heating elements, the resistance heating coils of which are imbedded in compacted magnesium oxide which is contained within a grounded, chrome-steel sheath. Each element shall be rated at 1 kilowatt at 230 volts alternating current single phase. The two elements shall be connected in open-delta for the three phase circuit. The maximum allowable sheath temperature shall be 1400 to 1500°F.

INTERCONNECTING PIPING

Description

The interconnecting piping shall be of as lightweight material as practical. It shall be adequately strong for the service intended and shall be sized to keep pressure losses within tolerable limits. Operating conditions such as temperature, pressure, location and application shall dictate the choice of material to be used. Every piping circuit of the liquid product generator shall be protected against excess pressure by means of pop safety valves.

AIR SEPARATOR INSTRUMENT PANEL

Description

The air separator instrument panel shall be fabricated by Air Products, Incorporated. It shall support pressure gages, liquid level gages and temperature indicators which shall serve as operating aids for the liquid oxygen generator. The instrument panel and its supports shall be fabricated of steel. Its measurements shall be approximately 30 inches long by 37 inches wide. The following instruments shall be flush mounted and readily accessible and demountable for service, if necessary.

High Pressure Column Pressure Gages

Low Pressure Column Pressure Gages

High Pressure Product Pressure Gages

Phase Separator Liquid Level Gage

High Pressure Column Liquid Level Gages

Low Pressure Column Liquid Level Gages

Air Separator Temperature Indicator

ELECTRICAL CONTROL PANEL

Description

The electrical controls shall be contained within a National Electrical Manufacturers' Association Type One enclosure, and all visual indicators and manual controls shall be flush mounted on the face of the enclosure cover. The electrical controls shall consist of the following: power distribution circuit breakers, an indoor switchgear unit complete with an alternating current voltmeter, ammeter, current transformer, and all controls necessary for alternating-current generator operation.

INSULATION

Description

The fiberglass insulation for the air separator shall be Owens-Corning Fiberglass Corporation Basic Fiber No. 28, Type E.

SECTION V
GENERATOR MASTER VALVE AND TEMPERATURE INDEX

For identification and reference purposes, the Generator valves and temperature indicators shall be assigned letter-and-number symbols. Insofar as possible, the letter in each valve symbol shall be the initial of the fluid normally controlled by the valve. The letters in each temperature indicator symbol shall denote the type of instrument used to determine the temperature. Temperature indicators shall be either dial thermometers, or millivolt-type, direct-reading pyrometers. This system of identification has been applied in the flow diagram of Figures 1, 2, 3 and 4.

<u>Symbols</u>	<u>Names of Valves</u>
<u>AIR VALVES</u>	
A1-A	Air Expansion to Oxygen Column
A1-B	Air Expansion to Nitrogen Column
A7	Expansion-Engine Air Inlet
A10	First-Stage Condensate-Trap Blow-Off
A11	Second-Stage Condensate-Trap Blow-Off
A12	Third-Stage Condensate-Trap Blow-Off
A16	Heat Exchanger Blow-Off
A20	First-Stage Pressure-Gage Shut-Off
A21	Second-Stage Pressure-Gage Shut-Off
A22	Third-Stage Pressure-Gage Shut-Off
A26	Air Flow Control
A30	Main-Air Shut-Off
A54	High-Pressure Blow-Down
A81	Moisture Accumulator Tank Drain
A84	Expansion-Engine Inlet Blow-Off
A86-A	Dry-Supply-Air Shut-Off
A86-B	Wet-Supply-Air Shut-Off
A104	High-Pressure-Air Exchanger Bypass
A105	Defrost-Air Exchanger Bypass
A106	Defrost-Air Exchanger Bypass Shut-Off
A107	High-Pressure-Air Leak Vent
A110	Expander Bypass
A111	Aftercooler Bypass
A128	Supply-Air Pressure Regulator
A129	Supply-Air Reservoir Drain
A130	Expander Discharge Column Feed
<u>OXYGEN VALVES</u>	
O1	Crude Oxygen Expansion
O7	Oxygen-Pump Feed Control
O10	Pure-Oxygen Test
O14-A	Low-Pressure-Oxygen-Column Defrost
O14-B	Low-Pressure-Nitrogen-Column Defrost
O20	Low-Pressure-Column Gage Shut-Off

021	High-Pressure-Oxygen-Gage Shut-Off
022	Pure-Oxygen Lower Liquid-Level-Gage Shut-Off
023	Pure-Oxygen Upper Liquid-Level-Gage Shut-Off
024	Pure-Oxygen Upper Liquid-Level-Gage Vent
025	Pure-Oxygen Lower Liquid-Level-Gage Vent
026	Crude-Oxygen Upper Liquid-Level-Gage Shut-Off
027	Crude-Oxygen Lower Liquid-Level-Gage Shut-Off
028	Crude-Oxygen Upper Liquid-Level-Gage Vent
029	Crude-Oxygen Lower Liquid-Level-Gage Vent
038	Oxygen-Liquid-Level-Gage Vent
039	Oxygen-Liquid-Level-Gage Vent
040	Oxygen-Liquid-Level-Gage Equalizer
050	Column-Pressure-Gage Shut-Off
084	Crude-Oxygen Upper Liquid-Level-Gage Vent
085	Crude-Oxygen Lower Liquid-Level-Gage Vent
087	Pure Liquid Offtake
094	Pure-Oxygen Liquid-Level-Gage Equalizer
095	Crude-Oxygen Liquid-Level-Gage Equalizer
0101	Hydrocarbon-Adsorber Inlet
0102	Hydrocarbon-Adsorber Outlet
0103	Hydrocarbon-Adsorber or Bypass
0108-A	Oxygen-Column Crude-Oxygen Feed Shut-Off
0108-B	Nitrogen-Column Crude-Nitrogen Feed Shut-Off
0118	Pure Gas Offtake
0131	Pure-Oxygen Subcooler Inlet

NITROGEN VALVES

N1-1	Oxygen-Column Crude Oxygen Expansion Valve
N1-3	Nitrogen-Column Crude-Nitrogen Expansion Valve
N12	Noncondensable-Gas Blow-Off
N13	Exchanger Defrost Outlet
N14-A	High-Pressure-Oxygen-Column Defrost
N14-B	High-Pressure-Nitrogen-Column Defrost
N15	Air-Separator-Jacket Nitrogen Feed
N20	High-Pressure-Column Gage Shut-Off
N30	Noncondensable-Gas Shut-Off
N37	Pump-Nitrogen Feed Control
N56	Oxygen-Pump Defrost Inlet
N83	High-Pressure-Nitrogen-Gage Shut-Off
N104	Hydrocarbon-Adsorber Defrost Inlet
N105	Hydrocarbon-Adsorber Defrost Outlet
N106	Expander Defrost Inlet
N108	Crude-Nitrogen Upper Liquid-Level-Gage Shut-Off
N109	Crude-Nitrogen Lower Liquid-Level-Gage Shut-Off
N110	Crude-Nitrogen Upper Liquid-Level-Gage Vent
N111	Crude-Nitrogen Lower Liquid-Level-Gage Vent
N112	Crude-Nitrogen Liquid-Level-Gage Equalizer
N117	Nitrogen-Column Noncondensable-Gas Shut-Off
N127	High Purity Nitrogen Test
N137	Pure-Nitrogen Subcooler Inlet
N142	Pure-Nitrogen Column Pressure Gage Shut-Off
N143	Nitrogen Pump Defrost Inlet
N151	Nitrogen Condenser Upper Liquid-Level-Gage Inlet

N152	Nitrogen Condenser Lower Liquid-Level-Gage Inlet
N153	Nitrogen Condenser Upper Liquid-Level-Gage Vent
N154	Nitrogen Condenser Lower Liquid-Level-Gage Vent
N155	Nitrogen Condenser Liquid-Level-Gage Equalizer

Symbol

Temperatures Indicated

THE THERMOMETER TEMPERATURES

TH1	Air Leaving First-Stage-Intercooler of Air-Compressor
TH2	Air Leaving Second-Stage-Intercooler of Air-Compressor
TH3	Air Leaving Third-Stage-Aftercooler of Air-Compressor
TH4	Air Leaving Oxygen-Vaporizer
TH5	Gaseous Product Leaving Vaporizer

GENERATOR MASTER VALVE AND TEMPERATURE INDEX

Symbol

Temperatures Indicated

TEMPERATURE INDICATING TEMPERATURES

T1	Air Entering (Air Leaving) Water-Heat-Exchanger
T2	Air Leaving (Air Entering) Water-Heat-Exchanger
T3	Air Leaving (Air Entering) Oil-Oil-Heat-Exchanger
T4	Air Entering (Air Leaving) Oil-Oil-Heat-Exchanger
T5	Nitrogen-High-Air Ratio Turbine-Exchanger
T6	Nitrogen-High-Air Entering Turbine-Exchanger
T7	Nitrogen-Liquid-Oxygen Entering Nitrate-Nitrogen Subcooler
T8	Nitro-Liquid-Oxygen Leaving Nitrate-Nitrogen Subcooler
T9	Defrost-Air Leaving Air-Expander
T10	Reheat-Air=Air Entering Hydrogen-wash step
T11	